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# Systems Analysis Department

## Annual Progress Report

## 1994




Edited by Hans Larsen and Kurt E. Petersen

Risø National Laboratory · Roskilde · Denmark
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# Abstract

The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1994. The department is made up of the Cognitive Systems Group, the Risk Analysis Group, the Energy Systems Group, and the UNEP Collaborating Centre on Energy and Environment. The report includes lists of publications, lectures and staff members.

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# Contents

# Introduction

By Hans Larsen

1994 has been a successful year for the department. The year can be characterised in the following way: high level of activity, strong expansion of the externally funded research contracts, and internal strengthening of the research profile.

1994 has also been a year of transition as Risø during the year has decided to change the organisational set-up within all research departments meaning that the former Groups are abolished. In the future the research activities are to be undertaken in the framework of focused research programmes. The aim of the new organisational set-up is to increase flexibility, and in principle all staff members of the department are now allocated to the individual programmes on an annual basis. This organisational structure was fully implemented by the end of the year.

The department up till now consisted of the four groups:

- Energy Systems Group (ESG)
- UNEP Collaborating Centre on energy and environment (UCC)
- Risk Analysis Group (RAG)
- COgnitive systems Group (COG)



In the new organisational set-up the research activities of the Systems Analysis Department are undertaken within the following research programmes, which to a large extent are synonymous with the above-mentioned former groups:

- Simulation and optimization of energy systems,
- Energy planning in developing countries (UCC),
- Integrated environmental and risk management and,
- Man/machine interaction.

The activities of the department are multidisciplinary, and research and development focus as in the previous years on methods and models dealing with the interplay between technologies, systems and humans.

Among the major events in 1994 the following in particular can be mentioned. The UNEP Collaborating Centre on energy and environment passed an international evaluation most successfully, and subsequently a memorandum of understanding was signed by Danida, UNEP and Risø on the continuation of the Centre, initially with funds for a new three-year period. The second phase of the UNEP Greenhouse Gas Abatement Costing Studies was finalised in 1994 and the department was responsible for organizing an international three-day conference in June 1994 in Copenhagen on National Action to Mitigate Global Climate Change; there were 170 participants from 60 countries. A major study has been carried out in collaboration with the Danish utilities ELSAM and ELKRAFT on the possibilities up to year 2030 for introducing fluctuating renewable energy into the Danish energy system on a large scale. In 1994 the department entered into a close collaboration with the man/machine division at the OECD Halden Reactor Project in Norway. Finally, it can be mentioned that through a formal collaboration agreement the department in 1994 has become strongly involved in the simulation activities at the Danish Maritime Institute.

The total staff numbers 46 engineers, natural scientists and economists as well as social and behavioural scientists, of which 22 are senior scientists or economists; in addition, there are seven supporting staff. By the end of the year eight staff members are enroled as Ph.D. students at various Danish universities, and one is a post-doctoral student. Two new Ph.D. students have been engaged and will start their projects in the beginning of 1995. During the year several foreign guest researchers from many parts of the world have visited the department for shorter or longer periods.

The activities of the department involve close collaboration with Danish and foreign universities, research institutes and industrial companies. During the year collaboration with other Danish institutions and universities has been strengthened, e.g. through formal collaboration agreements.



In addition to the Danish collaboration the department has a long tradition for undertaking research and development projects together with international organisations such as the European Commission, Nordic Council of Ministers, International Energy Agency (IEA), World Bank (WB), Intergovernmental Panel on Climate Change (IPCC), World Energy Council (WEC), United Nations (UN) and in particular United Nations Environment Programme (UNEP).

A significant part of the research in 1994 was carried out under research projects supported by international research programmes, such as the European Commission: ESPRIT, Environment and Joule.

## *Simulation and optimization of energy systems*

By Hans Larsen

The aim of this research programme is to undertake integrated assessments of energy, environment and economy in relation to the introduction of new energy technologies into complex energy systems.

In 1994 the research has focused on the development of methods that address the interplay between "top-down" and "bottom-up" modelling approaches, and methods for estimating environmental externalities, i.e. for calculating damage and abatement costs. Another, research project has been undertaken on internationalising energy markets and energy planning in Eastern Europe. Finally, projects have been carried out dealing with forecasting electricity demand in the service sector and the possibilities of introducing new environmentally benign energy technologies.

*World Energy Council Working Group 4c. (Chaired by Risø.) Meeting in Naivasha, Kenya, November 1994.*

1994 has been a year with a very high level of activity in the group. The volume of new projects has superseded expectations with the result that a few ongoing projects had to be prolonged. In the following highlights are presented of some of the major projects.

Research has continued examining the interplay between "bottom-up" and "top-down" modelling approaches. A project with support from the Danish Energy Research Programme was initiated in 1993, and is carried out in collaboration with the Ministry of Finance. The major activities in 1994 within this project concerned a so-called supply module for the Danish macro-economic model, ADAM. The project will be finalised in 1995.

In collaboration with the Technical University of Denmark a major study on external effects in utilising renewable energy has been completed. The study which was supported by the Danish Council of Renewable Energy was started in 1993. The first part of the study pays special attention to the theoretical aspects of the definition of externalities in relation to the energy system. The second part deals with the findings on externalities in connection with renewable energy, e.g. biomass and wind energy.

A study has been carried out in collaboration with the Danish utilities ELSAM and ELKRAFT, on analysing the possibilities up to year 2030 for large-scale implementation of fluctuating renewable energy into the Danish energy system. The work was completed by the end of 1994.

The post-doctoral project dealing with environmental planning under uncertainty has continued and included a six months stay at Lawrence Berkeley Laboratories in USA. The aim of the project is to analyse environmental planning activities both with regard to technical and policy management aspects in terms of the associated uncertainties, and to investigate how mathematical models can be used in planning.

In collaboration with the Meteorology and Wind Energy Department at Risø the group has participated in a Danida supported project in Egypt. The project was initiated in 1992 and will be finalised in 1995. The major role of the group has been setting up procedures which enable the Egyptian authorities to formulate a master plan for utilising wind energy, which is plentiful especially at the Red Sea.

In collaboration with several Danish partners a project has been continued on heat planning in the Katowice region of Poland. The project is financed by the Danish Ministry of Foreign Affairs, and runs from 1992 to 1995. The aim of the project is to propose changes in the technical installations, administrative procedures and in consumer behaviour, with the ultimate goal of improving the environment.

A project supported by the Danish Energy Research Programme "Danish Utilities in a Competitive Market" was initiated in 1993 in collaboration with Local Governments Research Institute (AKF) and Roskilde University. The work in 1994 has focused on the competitiveness of combined heat and power in an open European Market. The project will be finished in 1995.

Finally, the group has continued its work on an EC-supported project EURIO focusing on Central and Eastern Europe. The main tasks are to elaborate didactic tools as well as a model and training package of existing models.

The group has for many years been responsible for calculation of the emissions of pollutants to the air from Denmark. In 1994 two tasks were performed for the European Union: (1) implementation of the FOREMOVE model for the projection of emissions from road traffic in Denmark and (2) extension of the CORINAIR inventory to include the Baltic countries. By the end of the year through Risø's partnership in ENERO the group was selected to participate in the European Topic Centre on Air Emissions established by the European Environmental Agency.

A life cycle analysis project supported by the Danish Energy Research Programme is carried out in collaboration with Danish Energy Analysis on the development of a methodology for assessing the consequences of implementing energy saving technologies in industry. The project will be completed in 1995.

## *Energy planning in developing countries*

BY JOHN M. CHRISTENSEN

The new programme "Energy planning in developing countries" provides the institutional structure for the UNEP Collaborating Centre on Energy and Environment. The Centre is the dominant activity of the programme, and the common objective is to promote the incorporation of environmental considerations in energy planning and policy in developing countries. To achieve this the programme is engaged in:

- collaborative projects with national policy and research institutions in several developing countries
- providing capacity building support
- development of methodologies and tools for energy-environment and climate change mitigation analysis
- support to UNEP in particular on energy, climate and GEF activities

Activities at the Centre expanded considerably in 1994 and this trend is expected to continue in the coming years.

A necessary prerequisite for this development has been a very clear positive result of the independent international evaluation undertaken by UNEP in 1994, of the activities at the Centre during the first three and a half years of existence. This led subsequently to the signing of a new permanent agreement between UNEP, Danida and Risø on the continuation of the Centre with an underlying funding arrangement for initially three years.

Another important activity for the future work of the Centre has been the development of a new UNEP Energy policy, strategy and work programme. This work has been coordinated by the Director of UNEP's Industry and Environment Office, and was successfully completed in November. The Centre participated in both steering and advisory committees for the work and in addition provided ad-hoc support to the consultants. The policy will be presented to the UNEP Governing Council in May 1995 and when approved it will form the basis for UNEP's energy activities in the coming biennium.

While these two activities form the basis for the work in the coming years, the description below will focus on some of the major events and activities that took place in 1994.

In terms of support to UNEP's energy projects the major activity for the Centre has been to work with the team in China on the project "Incorporation of environmental considerations in energy planning in the PRC". As part of this collaboration the Centre hosted three project team members as guest researchers. From the national team a professor from Tsinghua University worked at the Centre for 6 months through an EC Post-doctoral Fellowship, and from each of the regional teams (Beijing and Guangxi) a project staff visited for a month. Most of this time was spent on informal training and collaboration on the application of the LEAP/EDB tool for the scenario analysis at both national and regional level.

In the similar project in India the Centre has more of a monitoring role and the engagement in 1994 has mainly been in the form of participating in project review meetings and presentation of the draft findings at a national workshop for policy makers.

The expansion of externally funded activities noted above has mainly taken place in the area of climate change mitigation.

Early in 1994 the Centre finished the reporting from the Phase II of the UNEP GHG Abatement Costing Studies with three volumes presenting the summaries of the ten participating national studies, the methodological guidelines and the main report containing the analytical findings, the comparative assessments and the established experience with the methodological work.

This work continues in a smaller Phase III focusing on broadening the methodological framework from mainly covering energy and $CO_2$ to also including other sectors and GHGs. This work is done in collaboration with national teams in Zimbabwe and Venezuela and with support from Lawrence Berkeley Laboratories (LBL), USA. The collaboration with LBL also included preparing a joint special issue for the international journal "Energy Policy" on Methods for the economic evaluation of GHG mitigation options, presenting the results of Phase II activities.

1994 was also the year where the Centre organized its first major international conference on "National Action to Mitigate Global Climate Change". The event took place from 7 to 9 June in Copenhagen and was attended by over 170 policy makers, planners and researchers from more than 60 countries worldwide and the key international institutions. The conference was sponsored by Danida, GEF, UNEP and Risø and the opening address was delivered by the Danish Minister for Environment.

Danida is also sponsoring two new climate change related activities in Africa: a national capacity building project in Burkina Faso based on a request by the Government, and a subregional mitigation assessment project in Southern Africa involving national activities in Botswana, Tanzania, Zambia and Zimbabwe and a specific regional component. Phase I of this latter project was completed late 1994 and the follow-up is under preparation.

The Centre has not only been diversified in terms of its activities, but also on the contract sponsoring side the past year has led to new collaborations with e.g. UNDP, US Environment Protection Agency, Commission of the European Communities, Deutche Gesellschaft fur Technische Zuzammenabeit (GTZ).

## *Man/machine interaction*

BY LEIF LØVBORG

The aim of the Man/machine interaction programme is to develop methods to analyse the interaction between people and advanced technical systems with a view to establishing concepts for the safe and efficient operation of complex work environments. An important research issue addressed by the programme is human performance within cognitively demanding and safety-critical work areas such as industrial process control, aviation, shipping and anaesthesia. Topics covered include human error analysis, MMI design and testing, and evaluation of the effects of simulator training. The research agenda furthermore encompasses methodologies of CSCW (Computer Supported Cooperative Work) emphasising work analysis and conceptual system design, prototyping and demonstration of IT support tools


for advanced manufacturing, emergency management and medical informatics.

The programme is carried out by an academic staff of ten with assistance from a technician. It is presently attended by a guest researcher from the University of North Carolina at Chapel Hill on a two-year fellowship sponsored by NSF and NATO. Two psychologists from Danish universities are attached to the programme as Ph.D. students. In 1994 a researcher from Tokyo Institute of Technology joined the programme for ten months through funding awarded him by the Japanese Government. Several graduate students have performed their masters thesis with support from programme staff and facilities.

A large proportion of the programme activities in 1994 was carried out in close collaboration with international partners from industry, universities and research organisations in projects of the Third EU Framework Programme and Eureka: Esprit Basic Research Action COMIC (Computer-based Mechanisms of Interaction in Cooperative Work), Telematics/AIM KAVAS-2 (Knowledge Acquisition, Visualisation and Assessment System), Environment MUSTER Multi-User System for Training and Evaluation of Environmental Emergency Response), Eureka MEMbrain (Decision-Support Integration Platform for Major Emergency Management) and Esprit MATE (Multi Aircraft Training Environment). Financial support of the research in CSCW was provided by the Danish Science Research Council under the framework programme 'Centre for Cognitive Informatics' executed jointly with Roskilde University.

The COMIC project passed its second year review with notable success. Risø's task within the consortium is to develop the theoretical foundation for the design of coordination mechanisms for CSCW systems. A significant achievement is a computational notation system developed in collaboration with the Department of Computer Science at the University of Milan. By the end of 1994 the Department entered a contract with the European Commission DGXII to serve as Coordination Agency for the COST-14 Action (CoTech) whose objective is to support the formation of a European CSCW research community.

The nearly completed KAVAS-2 project has resulted in a computer tool, KAVIAR, which helps medical researchers and practitioners formalise their domain knowledge and derive clinical classification procedures from data bases. Risø's main task in the project was to develop an advanced user interface for the tool in collaboration with Premium SA, Belgium. The KAVIAR prototype was demonstrated at the Telematics/AIM 1990-94 Final Conference in Lisbon.

A collaboration agreement has been entered into with the Danish Maritime Institute (DMI) concerning a joint R&D effort called HELT – Human Elements in Marine Operations. This initiative has its background in collision risks associated with ship navigation errors in heavily trafficked waters such as harbours and fairways crossed by bridges. The main component of HELT is an advanced human factors methodology for the evaluation of training sessions with navigator crews in the full-mission ship simulators at DMI. Collaborative undertakings in 1994 have included methodologies of CRM (Crew Resource Management) and task-network modelling of navigator performance. DMI and Risø are founder members of Danish Society for Simulator Training and Safety in Transport Industries (SimTrans), established in the summer of 1994 as a forum for the exchange of information between human factors specialists and people from shipping and aviation.

A milestone in the programme was the development of an advanced experimental system – MULTIMO – that makes it possible to analyse human action sequences in great detail from multiple video recordings integrated with the tracking of eye movements, as described later in this report. The MULTIMO concept and associated eye tracking technology have served as a useful platform for cooperation started with the Man-Machine Research Division of the OECD Halden Reactor Project in Norway.

Extensive material from the Department's research in man/machine interaction over the past several years is incorporated in a recently published book: Cognitive Systems Engineering (see list of publications).

## *Integrated environmental and risk management*

BY KURT E. PETERSEN

The aim of the research programme is to develop methods intended for analysing the safety and reliability of technical systems and to facilitate integrated environmental and management taking into account human and organisational aspects.

In 1994 the research was directed towards the three subject areas:

- development of methods for assessment of the reliability in design, operation and maintenance
- development of methods for assessment of the consequences of accidents at industrial plants
- development of methods for risk management at industrial plants and in local communities.

The goal is to address integrated evaluations of technical systems taking into consideration safety, environment, occupational safety, quality and economy. The focus is moving away from investigations at plant level in the direction of assessments within a geographical area taking into account multiple hazard sources, the infrastructure and regional planning aspects.

The year 1994 was characterised by a very high level of activity, resulting in a larger number of research projects than anticipated, and furthermore the activities resulted in a large number of international publications. Finally, two guest researchers contributed significantly to the progress and results within their research topics.

The work on the development of reliability methods was continued, focusing on reliability methods in design, operation and maintenance. Within the EU research programme TELEMAN, the main emphasis is on reliability in the design phase of telerobotic systems for work in hazardous environments. The reliability methods have been targeted to three specific systems: a gantry type of robot, a gripper simulating the capabilities of a hand, and a multi-legged small robot for inspecting the surfaces of walls and vessels. The work is based on the functional modelling technique at a stage where only functional requirements exist, but the detailed design is still undetermined.

In operation and maintenance the reliability methods were further developed in cooperation with the OECD Halden Reactor Project in Norway. The aim is to identify failures based on careful analysis of past experience combined with an intelligent review of component state measurements. An addition to the study is the development of interfaces for plant operators and maintenance staff to facilitate an efficient transfer of analysis results to practical guidance and support. Finally, a Ph.D. project has been started on the development of a method for assessing the reliability of control systems for process plants.

Human aspects are crucial in a number of risk analyses. A project on the evaluation of human aspects in marine off-shore activities was finalised in 1994 in cooperation with the Danish Maritime Institute and Statoil A/S. The human aspects were reviewed based on practical cases in the Norwegian sector of the North Sea, from where experience was obtained and where risk analyses have been carried out previously. The usefulness of simulator investigations and simulator training was emphasised. The work was partly sponsored by the Danish Energy Research Programme.

The second topic area is consequence analysis where the two main projects in 1994 were concerned with warehouse fires and dense gas dispersion. Projects within the EU Environment research programme focused on the characterisation of combustion products from warehouse fires using a facility set up at Risø suitable for small scale tests. A variety of substances, in particular pesticides, were tested to verify the usefulness of the test equipment to simulate warehouse fires, and to screen the substances prior to larger-scale testing, which was carried out in the UK and Sweden. The work was carried out in cooperation with the Department for Combustion Research. A part of the work is reported as a Ph.D. thesis.

The work on dense gas dispersion in 1994 was supported by two contracts within the EU Environment Research Programme. Field experiments were carried out with release of ammonia to study near-field buoyancy and the characteristics of the dense gas release. The experiments were finalised in the autumn. In another study experimental data from this and other EU research projects are collated and stored in a data base allowing a consistent treatment and statistical analysis. The work was carried out in cooperation with the Department of Meteorology and Wind Energy.

The work which was initiated on model quality assessment was continued partly within the dense gas data base project and partly in a contract for EU/DGXII, where an evaluation protocol for models used in major hazards assessment was finalised in 1994. The protocol will form a standard part of new contracts within major hazards research involving model development.

The research on risk management dealt with aspects of risk analysis in emergency planning as part of a EUREKA project. The work comprised the study of the use of risk analysis results in the selection and generation of accident sequences for simulator training of emergency response crews. A natural input is lessons from past accidents. A review of selected cases started in 1994.

During the last two decades research has been carried out in hazard identification methods and risk and reliability analysis tools. This activity in 1994 was focused on the development of a method to describe an industrial plant as a socio-technical system to facilitate a subsequent hazard identification able to identify failures related consistently to both structural, operational and managerial matters. The work was partly sponsored by the EU STEP Programme. A Ph.D. project has been started on the development of a method for assessing the safety culture at an industrial plant. The STARS tool will be commercialised in 1995 and an effort was started to initiate a follow-up activity utilising a risk analysis tool as a central component of a total risk management tool. A proposal is in preparation for the new EU Framework Programme.

Finally, the competence gained was then applied to a number of smaller studies for Danish industries and authorities concerning guidance in risk analysis, schemes for systematic information transfer on hazards, explosion accident investigations and risk analysis review.


Foto Boye Koch

**Energy Systems Group**

# Energy Supply Module Connected to ADAM

A national energy system can be considered as a large system relative to the overall national economy. Major changes in the energy system will therefore cause a variety of feedback effects in the macroeconomic system. It has been recognized in recent years that considerations of large-scale environmental reforms or changes in the structure of the international energy markets should be analyzed in a context that integrates the energy system and the macroeconomy. Models built for this purpose are usually called bottom-up/top-down models.

The present project is supported by the Danish Energy Research Programme, and it is carried out in cooperation between Risø National Laboratory and The Danish Ministry of Finance. The project was initiated in 1993 and is expected to be finalised in 1995. The study integrates BRUS a techno-economic simulation model of the total Danish energy system developed by Risø, and ADAM, a Danish macroeconomic model which is used for planning and policy evaluation by the Danish government.

The practical procedure of the project is to establish input-output linkages in ADAM as well as in a simplified version of BRUS, to make the two models communicate. The first input linkage from ADAM has been established; it determines the demand for electricity, heat and natural gas. This linkage is based on the existing input-output principles of ADAM, with a specified share of input in each sector supplied by electricity, heat and natural gas. All demand figures are converted to energy equivalents.

The supplies of converted energy, electricity and heat are evident issues in a bottom-up context using specified technologies, existing structure of production capacity etc. A bottom-up description of energy supply will enhance the analytic capabilities of the combined system both in respect to environmental issues and the macroeconomic consequences of changes in supply technology.

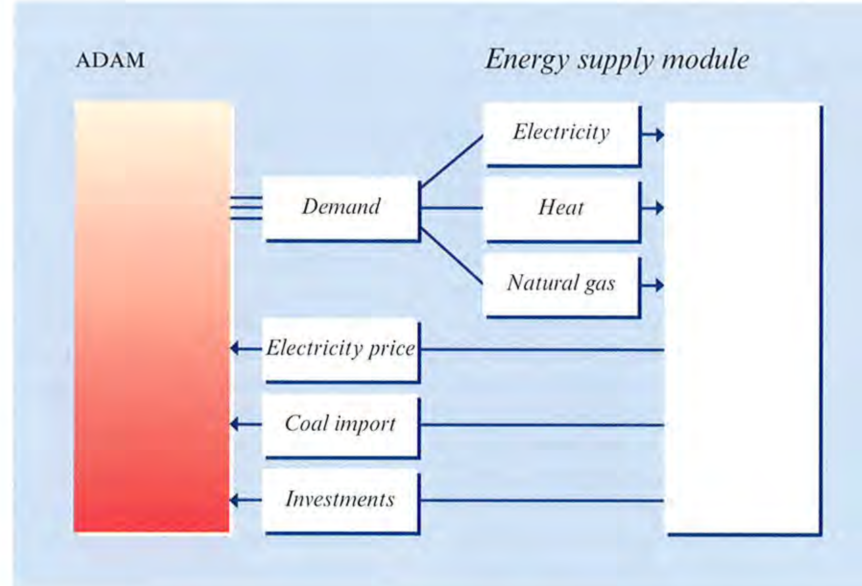
In 1994 a BRUS-module to ADAM has been developed describing electricity supply and capacity developments. In this module the development in the prices of electricity, heat and natural gas can be derived given an expansion plan of the supply system. These prices are given by the mix of technologies, efficiency developments and fuel prices. This module gives the opportunity to examine both price-demand effects due to price movements (carbon dioxide taxes) and specific expansion plans for electricity and heat production in the same model and with the same basic assumptions. Price changes resulting from variations in the supply system will be included as well.

The determination of prices is based on actual legislation. The basic principle of legislation is the non profit principle. This implies that prices are determined by equating total revenue with total costs. To form total costs the cost components must be identified and described. Fuel cost is calculated using actual electricity demand, fuel efficiencies, fuel prices and fuel distribution. Other fuel costs are net import of electricity given from the demand component in ADAM and an import price. Investment consists of plant investment and investment in distribution facilities. The price regulation of electricity includes a use of appropriation on investment up to 5 years ahead of the date of plant completion.

In the electricity sector the production capacity includes a 20% overhead on the peak load demand. A relation between total electricity demand from ADAM and peak load has been established with a slower growth of peak load than that of total demand. Investment is described assuming that actual production capacity will always equal the required production capacity including the 20% overhead. The necessary investments will be distributed over the previous five years ahead of the year the capacity must be available. Capacity includes several kinds of production categories and technologies. Development of the production capacity of wind, small CHP and industry-owned combined plants are projected directly. Large scale power plants are used to meet the necessary demand for electricity, and the investment cost for each technology is used to form the total investment cost of all production facilities.

### *Linking variables*

To yield the combined effect of changes in the supply system and demand from ADAM, a number of iterations have to be run. Operation of the supply module is based on the macroeconomic demand for electricity, heat and natural gas. In the module a number of variables are determined which again influence the macroeconomic system and demand for the energy.




*Linkages established between ADAM and the supply module.*

The various demands for electricity, heat and natural gas are determined in ADAM and are used as inputs in the energy supply module to determine the production capacity and actual production.

The electricity price is fed to the macroeconomic system and is one of the determinants of electricity demand. The demand responses to price movements are fed back to the energy supply module giving rise to another iteration of capacity determination, production cost and electricity price.

Fuel demand by the energy converting sectors are calculated and fed to the ADAM system. For example the import of coal is determined in the energy module, as the energy converting sector is the main consumer of coal. This is the main impact on external balances from the energy supply module to the macroeconomic model. At present only the import components of fuel demand are given. Fuel demand will be much lower according to this specification compared to the traditional input coefficients given in the ADAM specification, due to the detailed description of the technology, (fuel efficiency) used in new plants.

Investments in the sector are determined in the energy module and split in construction and machinery, which are the two categories in ADAM. Investment in each plant is distributed over the previous five years prior to completion according to a normal investment profile.

The work continues on determining the prices of electricity and heat output. Another issue to be examined is the importance and the possibilities for treating foreign trade in electricity. It is examined if some of the new fuel demand categories, like straw or wood, could be linked to the macroeconomic sectors. This linkage could be interesting in viewing the impact of using a large share of biomass in energy conversion.

Henrik Jacobsen and Peter Stephensen

# Can the Danish Electricity Supply Industry Compete in an Open European Market?

The likely consequences of competition on a European scale for the Danish electricity supply industry are studied in a project "Danish Utilities in a Competitive Market" for the Danish Energy Research Programme with participation from AKF – Local Governments' Research Institute, Roskilde University and Risø.

The project was begun in 1993 and will be finished early in 1995.

In 1994 the research group conducted a series of interviews with executives in the electricity, gas, and district heating industries to disclose views and expectations with respect to the development of a competitive market for energy. Major concerns in the industry are the environmental targets of the Danish environmental policy and the competitiveness of the widespread use of combined heat and power (CHP) in Denmark. The report will be published by AKF early in 1995.

The main task of Risø has been to integrate our modelling experience with a quantitative analysis of the possible change of the organizational framework. In 1994 the focus has been the competitiveness of CHP. Preliminary results were presented at the Annual Conference of the IAEE (International Association of Energy Economists) in Stavanger; the report was published by AKF in November.

### *Electricity markets in the Nordic countries and proposals for the European Union*

Competition is now being introduced in the other Nordic countries, and the European Council is discussing a directive on limited competition in the Union. It means that the hitherto vertically integrated industry will be separated into production, transmission, distribution and sales. Production and sales will be open to competition. The network services, transmission and distribution will continue as regulated monopolies.

In addition to Denmark, the area of study includes Finland, Norway, Sweden and Germany. Transmission lines for exchange of power have already existed for many years, and several new lines are being constructed or planned.

The institutional conditions of international competition are discussed. We examine it by creating three different scenarios for a future northern European market for electricity:

1. status quo,
2. the model of limited competition proposed by the European Commission, and
3. integrated market for power where distributors and customers have free access to all suppliers.

Market Concentration is an important structural aspect. The present degree of concentration of the market for power supply differs very much among the northern European countries.

### *Very different structure of electricity generation technologies in northern Europe*

In northern Europe, electricity is generated using many different technologies: hydropower, nuclear power, condensing power (coal and gas fired electricity-only plants) and combined heat and power (CHP) are the most important. The very different operating conditions and cost profiles of these technologies are likely to have a strong impact on the future dynamics of competition.

It is crucial to distinguish between the short and long term. National policies of capacity expansion and pricing have resulted in a considerable overcapacity. In the short term, wholesale prices are therefore likely to be determined by short term marginal costs. Hydropower has far the lowest marginal costs in the short term (0.01-0.02 DKK per kWh) whereas condensing power is the most expensive generating technology (0.12-0.19 DKK per kWh within the range of fuel price forecasts until 2010). Nuclear power and CHP with all benefits assigned to the power (see Figure 1) have short-term marginal costs in between (0.06-0.11 DKK per kWh). Changing fuel prices and environmental restrictions or taxes will change the cost order between different generating technologies.

### *Short-term marginal cost or system-λ*

The price of the total supply system is determined by the short term marginal cost of the last plant that is necessary to satisfy demand at a given time. This is often called system-λ. The low-cost technologies (nuclear, CHP and in particular hydropower) are not likely to set the price very often within a





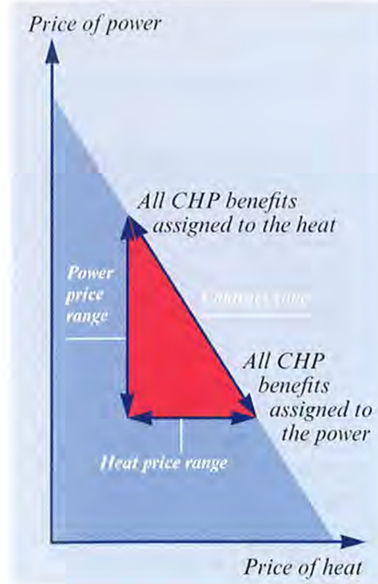



*Figure 1. Price flexibility for combined heat and power.*

northern European market. Normal demand will be too large to be satisfied by these technologies alone. Therefore, the more expensive coal and gas condensing power will determine system-λ most of the time.

In the longer run, demand will increase and supply will decrease as more and more plants reach the age of retirement. The price of electricity will therefore be pushed up to a level where it becomes profitable to construct new generating capacity. A combination of high capacity costs and political restrictions does not make hydro and nuclear power obvious choices in this situation. New generating capacity is more likely to be in the form of condensing power and CHP.

Prices and output are determined by the total interaction of demand and supply (including transmission costs). Norwegian researchers have developed models to determine equilibrium prices and output on a future competitive northern European market. All these models assume perfect competition; thus, as there is overcapacity, prices are determined by short term marginal costs.

### *The volume of foreign electricity trade*

It is common to expect that competition will create an increasing amount of foreign trade. But the opposite might be the case. This is particularly so in the long run. The explanation is quite simply that it is cheaper to transport fuel than to transport power. As new capacity mainly will be condensing power and CHP, it is most profitable to place it close to the consuming centres. Countries will therefore have few incentives to specialize in power production for export.

This argument does not apply to short-term exchanges of excess power, where exchange between different technologies can be very profitable. This is particular relevant for northern Europe with its large supplies of hydropower. Water can be stored and generation can quickly and costlessly be regulated. Producers of thermal power can avoid expensive peak plants by 'pumped storage' agreements with producers of hydropower.

### *Danish CHP is competitive, but the profit margin may be too small*

Future Danish power production will be dominated by CHP, either as coal or gas fired extraction-condensing plants or as back-pressure plants. The former technology permits a flexible combination of heat and power that is crucial for large base-load plants, whereas the latter technology is suitable for smaller units, typically combined cycle gas turbines, which are carefully dimensioned for a particular heat market with a diurnal storage for heat that allows operation only during hours with high or peak electricity load.

Our conclusion is that these power stations will be competitive in an integrated northern European market. Their short term marginal costs are below the equilibrium prices calculated by the Norwegian models, even when all CHP benefits are assigned to the heat. For the longer term, higher prices make it profitable to construct new plants. To exploit an economic potential for competition, Danish CHP producers must possess the necessary financial and regulatory freedom that is not provided by the present Electricity Act. The competitiveness of Danish CHP also assumes sensible economic dispositions by the utilities. The expected price levels are tight, and inefficient investment will lead to contribution margins that are too low to meet financial obligations.

### *Competition versus environmental policy*

Competition in the electricity sector could well be in conflict with environmental goals. These conflicts may be avoided by regulatory and economic measures. This issue is being discussed and will be analysed by using the available quantitative modelling methods. The reports on methods and results will be published in the first half of 1995.

*Publications 1994: 10, 11, 31 and 32*

Poul Erik Grohnheit

*The KONTEK 600 MW High Voltage Direct Current (HVDC) connection between Bjæverskov (Zealand, Denmark) and Rostock (Germany).*

# Environmental Damages caused by Energy Production – Externalities

The production of energy gives rise to different types of damage to the environment depending on the energy production technology. The common term for the costs of these environmental damages are externalities, which are costs not included in the price paid by the producer and consumer. A project has been carried out in collaboration with the Technical University of Denmark with the purpose of assessing both the environmental damages and external costs in the production of energy. The project was initiated by the Council for Renewable Energy and has been financed by the Danish Energy Agency. Two case studies have been considered in the project:

- A wind energy case, where wind turbines substitute a coal-fired condensing plant.
- A biomass case, where a combined heat and power plant fueled by biomass substitutes a small-scale natural gas-fired CHP plant.

In the project the environmental damages are thus compared, and externalities in the production of energy using renewable energy and fossil fuels are identified, estimated and monetized. Only the environmental externalities have been assessed in the project.

### Methodology

The methodology which has been used in order to find and monetize the environmental externalities consists of the different processes shown in Figure 1.

The identification process involves a description of all the processes in the production of, for instance, energy from windturbines, an assessment of the environmental influences and the damages these influences cause. The quantification process is a quantification of the identified influences, for instance the amount of $CO_2$ emitted from a coal-fired plant. The effects on the environment from the quantified influences are assessed as dose-response functions. An example of this is the assessment of how the emission of $SO_2$ results in acid rain, and how the damage from the acid rain affects forests in terms of timber lost. In the valuation process the aim is to assess the monetary value of the damages, that is estimate the price of corn (yield), the price of fresh water, the price of human life etc. All together, these assessments lead to the monetizing process of the externalities.

A serious problem in assessing the extent of the externalities is the uncertainty related to the assessment. The uncertainty is due to different conditions, as 1) insufficient knowledge of the dose-response effect, 2) the time horizon, and 3) irreversibility. It is possible to reduce the first kind of uncertainty by additional research in this area, but it is impossible to reduce the uncertainty related to a time horizon. This means that all the externalities are subject to uncertainty, and the externalities have therefore been estimated in an interval.

The energy technologies which have been assessed are the following:

- A 500-kW wind turbine and a smaller wind park of 5 MW, comprising 10 wind turbines.
- A 350-MW coal-fired conventional plant with desulphurisation plant and de-nox burners.
- A decentralized CHP plant with fluid-bed gasification based on wood chips followed by a gas turbine and a steam turbine. The power rating is 40 MW.
- A CHP plant based on natural gas with a power rating of 45.6 MW.

For each of the technologies different processes have been assessed in the identification process:

- Construction and establishment of the plant
- Fuel cycle
- Operation and maintenance of the plant
- Scrapping of the plant

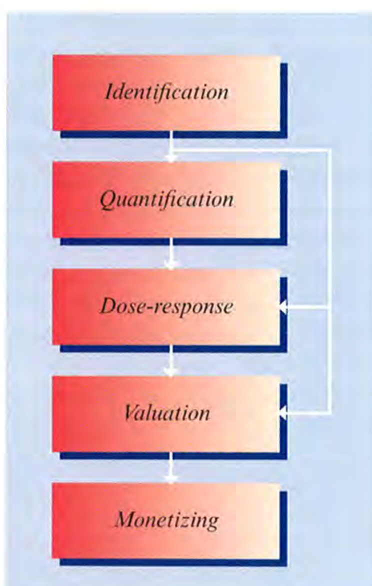



*Figure 1. Methodology for monetizing externalities.*



*Example of monetizing externalities.*

| *Monetized externality* | *Influence* | *Dose-response* | *Value* |
|---|---|---|---|
| *Costs of loss in fresh water* | *$CO_2$ (ton/GWh)* | *Loss in fresh water ($m^3$/ton $CO_2$)* | *Price of fresh water ($/$m^3$)* |

For each process an identification of the environmental influences and damages has been carried out, and the most important influences have been quantified.

### Monetizing of externalities

The monetizing of the externalities is carried out based on the quantification process, the dose-response process and the valuation of the damages. The monetizing may be expressed in the following way:

Monetizing of the externalities = amount · dose-response · price

The amount is the quantified influences for each energy technology, dose-response is the damage that the quantified influences produce per unit, and the price is the price per unit damage. An example of the monetizing is shown above.

There is a considerable difference in the way that the local and regional externalities and global externalities have been assessed. This applies to both the methodological way and uncertainty about the available data. The local and regional externalities have an effect on medium term, where both emissions and damages are known with a reasonably certainty. Regarding the global externalities the emissions are well known, but the extent of the damages is based on long-term scenarios for the development of the concentration of $CO_2$-emission in the atmosphere, and the rise in global temperature this will cause. The values associated with the damages are very uncertain as well, due to the long-term scenario. Because of this the total monetizing process has been divided into two categories: local and regional externalities and global externalities.

### Monetizing local and regional externalities

The quantified local and regional influences are the following:.

*Local*
Emissions to air (particles)
Influence on residences
Increased traffic
Increased wear on roads

*Regional*
Emissions to air
($SO_2$, $NO_x$, NMVOC)

The monetized local/regional externalities are shown in figure 2.

In general there is a considerable variation in the dose-response estimate, often a factor 3-4 between low and high estimate. The main reason for this variation is that the categories are very inhomogenous. The estimates of most of the costs are quite reliable, but some of the estimates are uncertain. For instance, the damages to buildings and monuments differ by a factor 7 from a low to high estimate.

### Monetizing global externalities

The global emissions, that have been quantified are $CO_2$, $CH_4$, CO and $N_2O$. These emissions have been converted to $CO_2$ equivalents by means of Global Warming Potential factors (GWP):

Wind power:
11 - 27 g
$CO_2$ equivalents /kWh

Coal:
875 - 1018 g
$CO_2$ equivalents /kWh

Biomass:
63 - 150 g
$CO_2$ equivalents /kWh

Natural gas:
382 - 415 g
$CO_2$ equivalents /kWh

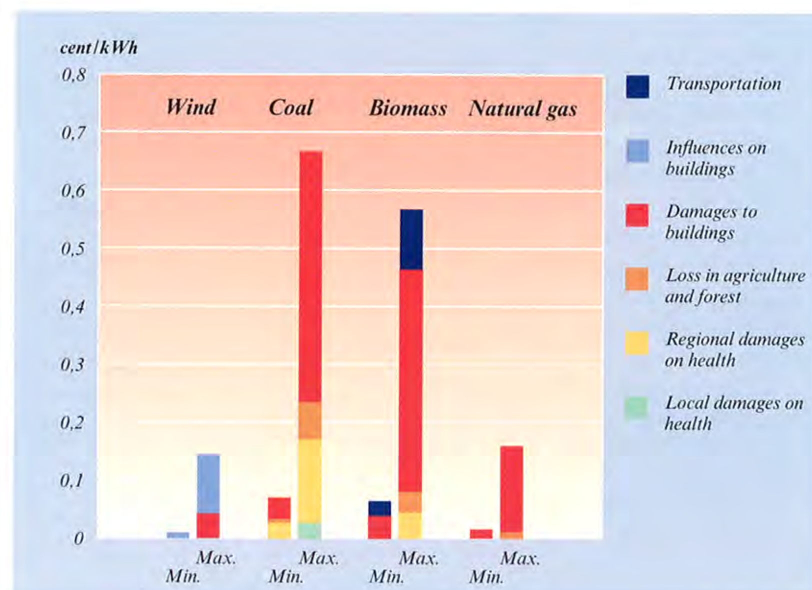



*Figure 2. Monetized local and regional externalities.*

The dose-response for the global emissions for the year 2045 is shown in Table 1. This year represents a time horizon of approximately 50 years, equivalent to a doubling of the concentration of $CO_2$ in the atmosphere (the case normally assessed in an analysis of this type). The estimates are based on the damages in year 2045.

| *Consequences* | *Year 2045 (damage/Gton $CO_2$)* |
|---|---|
| *Increased mortality* | *5,500 - 22,000 dead* |
| *Loss in fresh water* | *$0.3 - 2.7^{x} \times 10^{10}$ $m^3$* |
| *Loss in agriculture* | *$0.9 - 3.8^{x} \times 10^{6}$ ton yield* |
| *Loss in sealand* | *80 - 230 $km^2$* |
| *Loss in mainland* | *40 - 120 $km^2$* |

*Table 1. Dose-response for global emissions.*

Figure 3 shows the monetized global externalities for the year 2045.

The largest part of the monetized global externalities is related to an increase in mortality because of climate change. Loss in fresh water also constitutes a considerable part of the global externalities.

| *Energy Production Technologies* | *Estimated External Costs yearly average* |
|---|---|
| *Coal* | *0.2 - 2.6 ¢/kWh* |
| *Wind* | *0.02 - 0.2 ¢/kWh* |
| *Biomass* | *0.08 - 1.1 ¢/kWh* |
| *Natural gas* | *0.07 - 0.95 ¢/kWh* |

*Table 2. Total external costs for different energy production technologies.*

### *Conclusion*

The main results of the assessment of the external costs for the different energy production technologies are given in Table 2.

The estimates are average annual over a period of 50 years (year 1995 - 2045), and the numbers differ therefore from the above-mentioned global and local/regional externalities, where the global externalities are for the year 2045. The average has been calculated on the assumption of a linear connection between the $CO_2$ concentration for the year 2045, increase in temperature and the damage hereby. This assumption might tend to overestimate the average yearly damage, if the actual damage function between $CO_2$ concentration and damage is exponential. The assumptions are based on IPCC estimates for a doubling of the concentration of $CO_2$ in the atmosphere.

By far the largest external costs are related to the emission of greenhouse gases, especially $CO_2$, accounting for more than half of the total damage. This is due to the large economic consequences of the rise in temperature related to the greenhouse gases, e.g. rising sea level, reduced yield and increasing morbidity. The effects of local and regional pollution as, for instance, acid rain play a smaller role. This fact points in the direction of the need for further research into the relationship between rising $CO_2$ concentration, temperature and economic consequences.

*Publications in 1994: 22 23 and 24*

Henrik Meyer,
Poul Erik Morthorst and
Lotte Schleisner

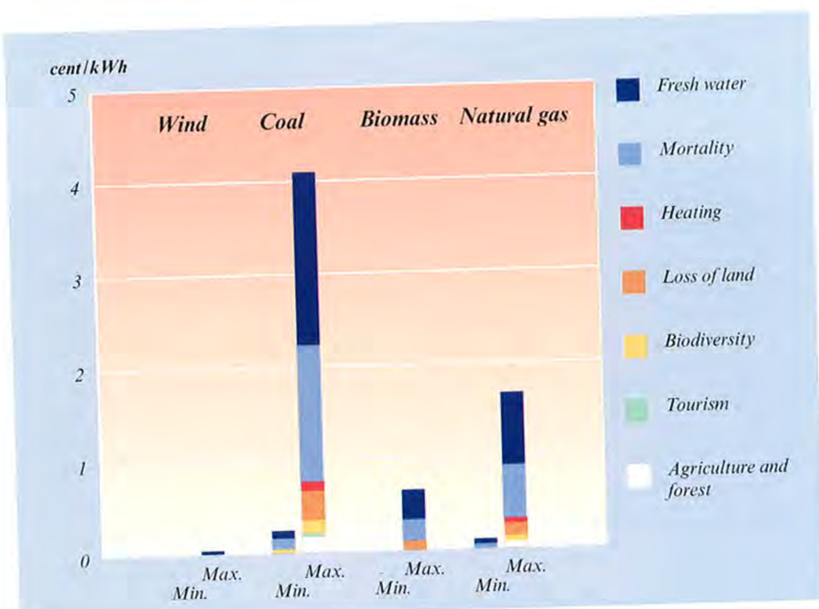



*Figure 3. Monetized global externalities year 2045.*





# Renewable Energy for Large-scale Power and Heat Production

Utilisation of renewable energy for large-scale power and heat production in the future Danish energy system has been analysed in a project carried out in collaboration with The Test Station for Wind Turbines and the electric utilities ELKRAFT and ELSAM. The project has been supported by the Danish Energy Research programme. The project was initiated in 1992 and finalised December 1994.

The main question addressed in the project is whether technically well-functioning electricity supply systems capable of providing the same quality of electric service as exists today can be developed on a timescale up to year 2030, based mainly on inputs from renewable energy technologies such as wind power, photovoltaic and biomass. $CO_2$-emission reduction and average production costs of electricity in future systems that integrate large-scale renewable energy utilisation are evaluated.

### *Approach*

The work has been based on a scenario approach starting out from verbal descriptions of basic aims in society at large. From this, consequences for the energy sector are derived on e.g. economic growth, fuel price developments, energy demands and energy supply strategies. Early in the project a seminar was held where a number of experts mainly related to different parts of the Danish energy sector were invited to contribute their expectations for a consistent development of consequences for the energy sector on such basis as noted above.

A main scenario, called "The Green Society", for the development of society at large was assumed that sets up fundamental assumptions for the analysis of large-scale utilisation of renewable energy. Defined here, this scenario mainly implies for the energy sector an assumption of a persistent political willingness to promote energy conservation and utilisation of renewable energy resources. An essential goal is to achieve substantial $CO_2$-emission reductions. Within this scenario, strategies for energy conservation and energy supply are developed. The analyses focus on the years 2005 and 2030, medium and long term, respectively. In the "The Green Society" a main goal is to achieve a renewable energy utilisation covering 75% or more of the expected Danish electricity demand in year 2030. A mile-stone towards this goal is to reach a 25% coverage of the electricity demand in year 2005 from renewable energy supplies, where wind power and biomass each cover half.

Three long-term electricity supply strategies for utilising renewable energy supplies have been set up. Two strategies (S1: wind 50%, biomass 25% and S2: wind 25%, biomass 50%) put main emphasis on wind power and biomass utilisation, respectively, and aim to cover 75% of the electricity demand from renewables in year 2030. The third strategy (S3: wind 50%, biomass 35%, solar 15%) combines the three main renewable energy supplies in Denmark and aims to cover the total demand for electricity by 2030.

The robustness of the strategies in the "The Green Society" for a transition towards large-scale utilisation of renewable energy in the electric system is tested on a medium-term basis in year 2005. Two further scenarios for the development of society at large are formed as the basis for this test. In short these scenarios can be characterised by their names: "The Unlimited Society" and "Society in Crisis". The strategies formed within "The Green Society" are thus analysed when subjected to altered basic preconditions as determined by the two alternative scenarios.

Four models have been used to carry out the analyses. These are the BRUS model for energy, economic and environmental analyses of the overall system, the supply system simulation models ES³ and SIVAEL and the PSS/E model for a Load Flow analysis of the electric grid.

BRUS is a scenario model that covers the total energy system and BRUS integrates actions on both the demand and supply side of the energy system. The model operates in time steps of one year or more and includes e.g. economic relations relevant for a long-term analysis of the system. ES³ is a simulation model for consequence analysis of the overall power and heat supply system on an aggregated level of description. Simulations cover one year in hourly time steps and are based on a defined operation strategy for the technologies involved. The SIVAEL model optimises the operation strategy in detail for the individual production plants in the power and heat supply system. Variable costs are minimised based on a simulation of the system in one-hour time steps covering typically one week. PSS/E contains a number of sub models for a detailed analysis of electricity systems and in particular the electric grid.

The following description focuses on the main assumptions in "The Green Society" for the heat and electricity demands and on the long-term supply strategies for heat and power. Furthermore, some main results on $CO_2$-emission and economic consequences for year 2030 are described.

### *Energy demand*

The result of making detailed assumptions on, e.g. economic growth and energy conservation is a total electricity demand close to today's level during the period up to year 2030. Increasing efficiency in the use of electricity almost compensates for the assumed increase in the demand for electric services in "The Green Society".

District heating demands are however expected to fall substantially during the period. Decentral combined heat and power generation will expand to still smaller district heating areas but further heat conservation actions in the building stock will tend to reduce the demands. In larger urban areas increased heat conservation measures are introduced. This is mainly due to changes in the supply structure of the energy system and the expected technological development towards higher electricity generation efficiencies. The heat demand in the CHP-system in "The Green Society" is expected to decrease by 40-50% during the period.

### *Technologies and supply strategies*

An assessment of the development of wind technology has been carried out. Improved design and efficiency are expected to reduce the specific kWh costs from wind turbines by about 25% during the period. The unit size of typical mass-produced wind turbines is expected to increase from about 0.5 MW as seen today to about 2.5 MW in year 2030, and the future wind turbines are expected to operate at maximum efficiency over a wide wind speed range utilising variable speed and active pitch controls.
It is assumed for the technical analyses of future Danish electricity supply systems that interaction with the electricity systems in our neighbour countries are kept at today's level. Thus, the need for increased regulation capability in the system mainly due to the large capacities of fluctuating wind power must be supplied from within the Danish system. Using peak load capacity fuelled by natural gas, this will increase the need for capacity in the transmission grid for gas.

To reduce to a minimum the excess electricity production from the fluctuating renewable energy sources and to maintain a high quality of supply, it is important that the rest of the generating capacity in the system has a high regulation capability. The desired combination of high regulation capability and high efficiency for electricity production points in favour of gas fuelled technologies. Gas technology is expected to play an important role in the future energy system, where high energy efficiency and system flexibility are essential.

In "The Green Society" the main new technologies introduced on the medium-to-long term are biomass gasification and fuel cells on natural gas and syngas. Based on these technologies the biomass utilisation in the system can be expected to yield high efficiencies for electricity generation. In the transition period, short-to-medium term, combined cycle plants on natural gas and CFB-plants or multifuel plants utilising biomass are introduced. Gas turbines supply peak load generating capacity to the system.

Heat storages are utilised to decrease/eliminate constraints for the combined heat and power production. Furthermore, the heat storage capacities are used in combination with heat pumps. "Excess" electricity production from, e.g. wind turbines is partly recovered by heat pumps and resistance heating to supply the district heating systems. If further heat production is required the heat pump capacity is used and electricity production is raised to supply the heat demand.

These general characteristics of the supply system apply to the three strategies analysed. Thus the strategies mainly differ by the relative intensity in utilisation of the renewable energy sources.

### *Electricity production*

The coverage of the electricity demand in energy terms in year 2030 by the main production plant categories in the three strategies is shown in figure 1.

"Excess" electricity production and additional electricity production to operate heat pumps are included both above and below the x-axis in figure 1. Approximately half of this production in the wind strategy S1 and in the strategy S3 (wind, biomass and solar) is consumed by the heat pumps, and in the biomass strategy S2 all of this production is recovered by heat pumps.

What remains of the "excess" electricity production is highly irregular in time and fluctuates strongly in the power. A fraction of this is recovered as resistance heat and what now remains is not usable by the system. Such losses occur in the strategies S1 and S3. In practice however, this potential production will be avoided since the wind turbines must be able to regulate down the production to maintain the stability on the national grid.





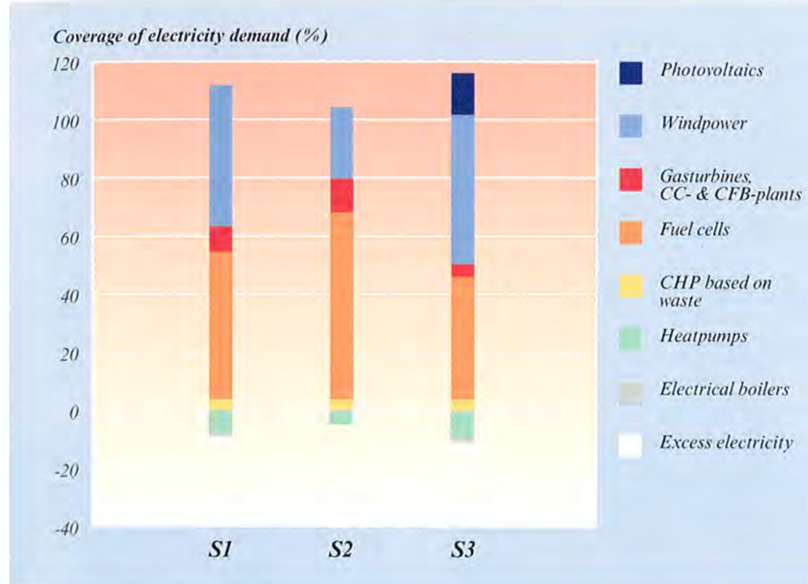



*Figure 1. Coverage of the electricity demand year 2030 from technology categories and "excess" electricity utilisation.*

### *$CO_2$-emission*

The achieved $CO_2$-emission reductions in the energy system as a whole and in particular in the combined heat and power sector are shown in figure 2.

$CO_2$-emissions from the power/CHP sector are reduced, respectively, with 85%, 88%, and 100% in the strategies S1, S2 and S3 relative to the 1992 level. For the energy system as a whole in year 2030 the emissions are reduced with 60-70%, which also includes the effects of energy conservation measures outside the CHP-sector in "The Green Society".

### *Costs*

The average production cost of electricity in 2030 in the strategies S1 and S2 are expected to increase about 30%, and for S3 about 65%, all relative to the 1992 level. As is often the case when combined heat and power production is involved, it has been assumed that the specific value of the heat produced is half the production cost of electricity. The composition of the average production costs in the strategies year 2030 is changed towards increased investments and a reduced dependence on the cost of fuel.

These cost estimates do not include investments to strengthen the medium voltage part of the electric grid (50/60 kV) which could be required when the mode of operation of the grid is changed due to the large installed wind power capacity. Investments to strengthen the lower voltage part of the electric grid (10 kV) are included.

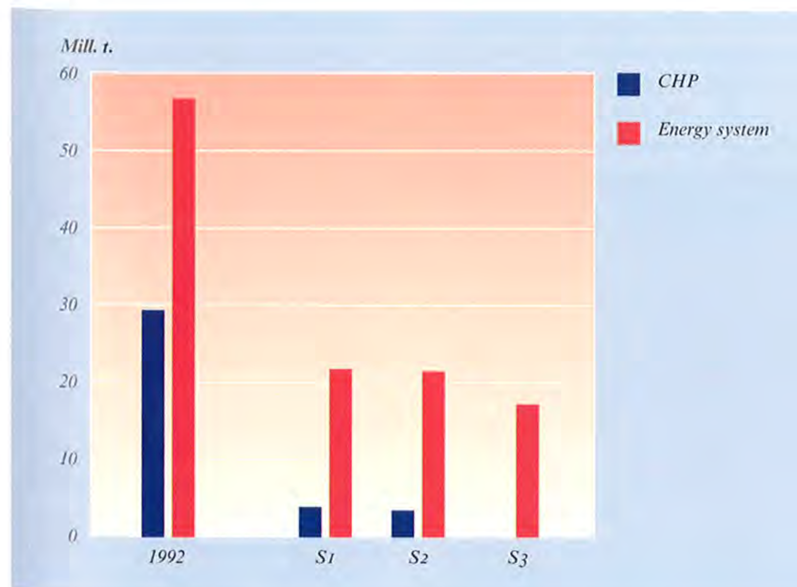



*Figure 2. $CO_2$-emissions from the total energy system and from the power/CHP sector in particular year 2030 in the three strategies compared to the 1992 emission level. Mio.t.*

### *Main conclusions*

A main conclusion from the technical analyses carried out is that it is possible over the period up to 2030 to develop well-functioning power and heat supply systems where a large part of the electricity supply is based on Danish renewable energy resources. However, the average production cost of electricity in 2030 is expected to increase substantially, relative to the 1992 production cost.

Poul Erik Morthorst and
Lars Henrik Nielsen

# ELSE – A Computational Tool for Forecasting Electricity Demand in the Service Sector

Through a number of years the demand for electricity has grown rapidly in the service sector, among other things because new processes and appliances have been taken into use in the sector at a high pace. It has been difficult to identify the driving forces behind this development, mostly because the services produced in the sector by nature are very different, and because the related electricity consumption is split into a large number of different end-use technologies.

In 1992 the Energy Systems Group initiated a project on the development of a computational tool for analysing and forecasting electricity in the service sector. The project was financed by the Danish Ministry of Energy and was finished in 1994.

The main objective of the project was to analyse the development in electricity demand in the service sector, and using this as starting point to develop a model for forecasting and sensitivity analyses. The model, ELSE, (model for ELectricity demand in the SErvice sector) provides the user with possibilities for:

- establishing a baseline scenario given data for the driving parameters,
- developing a number of alternative scenarios in comparison with the baseline,
- performing a number of sensitivity analyses for important parameters.

The ELSE-model has a unique feature of combining the econometric top-down approach with the bottom-up approach, based on simulation techniques. The model is developed in two levels: level 1 consists of the four main categories in the service sector: retail trade, wholesale trade, private services and public services. These four categories are analysed using econometric methods, and equations based on driving parameters are established. In general the equations are specified as:

$$\ln(E_t) = a_0 + a_1 \ln(Q_t) + a_2 \ln(P_t^E) + a_3 \ln(T_t)$$

where electricity demand ($E_t$) is explained by the development in production ($Q_t$), the relative price of energy ($P_t^E$) and technological change ($T_t$). $a_0$ - $a_3$ are the estimated coefficients.

A number of different specifications are estimated using different sample periods to test the stability of the coefficients. In general, production elasticities are estimated to be between 0.8 and 1.4, while price elasticities are fairly low, between - 0.05 and - 0.4.

In level 2 the main categories for private and public services are split into a number of subbranches. Private services are split into three subbranches and public services into seven subbranches, such as "Public works", "Water treatment plants", "Education and research" and "Social Institutions". These subbranches are modelled using simulation techniques, based upon physically related driving parameters.

The bottom-up equations are in general specified as:

$$E_t = E_{t-1} \cdot A_t \cdot \left[\sum_{i=1}^{n} S_{i,t} \cdot I_{i,t} \cdot F_{i,t}\right]$$

where electricity demand ($E_t$) is explained by previous periods electricity demand ($E_{t-1}$), the development in the chosen activity parameter ($A_t$) and the end-use specific development in intensity of use ($I_{i,t}$) and efficiency ($F_{i,t}$). Finally, the share of the end-use ($S_{i,t}$) is specified in the equation. Of course, the activity parameter chosen depends on the sub branch, e.g. for "Education and research" the driving parameter is the demographically determined development in the number of pupils.

Figure 1 shows the results of the computations performed at the two levels. The lower curve shows the forecast for electricity demand in the service sector given by the econometric approach, the upper curve shows the results by the bottom-up approach.

The computed discrepancy (the shaded area in Figure 1) can be treated in different ways in the model.

- A. The given (uncertain) assumptions can be evaluated and eventually changed to diminish the discrepancy
- B. If all assumptions are evaluated to be reasonable, the model can compute a weighted average of the results of the two approaches
- C. The calculated discrepancy is accepted as (part of) the uncertainty related to medium-term forecasts.

The above-mentioned procedure for removing of discrepancies is specially developed to facilitate the discussion process towards attaining a consensus in working groups for establishing energy forecasts. The ELSE model makes it easy to compute the consequences of alternative assumptions on driving parameters, to perform a sensitivity analysis on assumptions on efficiency improvements and development of energy prices. Finally, the macro part of the model is related to the Danish macro-economic model, ADAM, used by the Ministry of Finance for the official economic projections in Denmark; the model makes it possible to calculate the consequences on electricity demand in the service sector of new macro-economic forecasts for Denmark.

Figure 1 shows the overall results for electricity demand of the reference scenario using the top-down and bottom-up approach. The discrepancy between the two approaches amounts to appr. 10% in the year 2010. The total electricity demand in the service sector is calculated to increase by approximately 1.8% p.a. until year 2010.

Figure 2 shows an example of a subbranch calculation. "Social Institutions" include day nurseries, kindergartens and rest homes. Total electricity consumption is calculated to decrease after year 2000, due to a decrease in the number of children and an increase in end-use efficiency. The share of lighting is calculated to decrease slightly, while that of ventilation will increase.

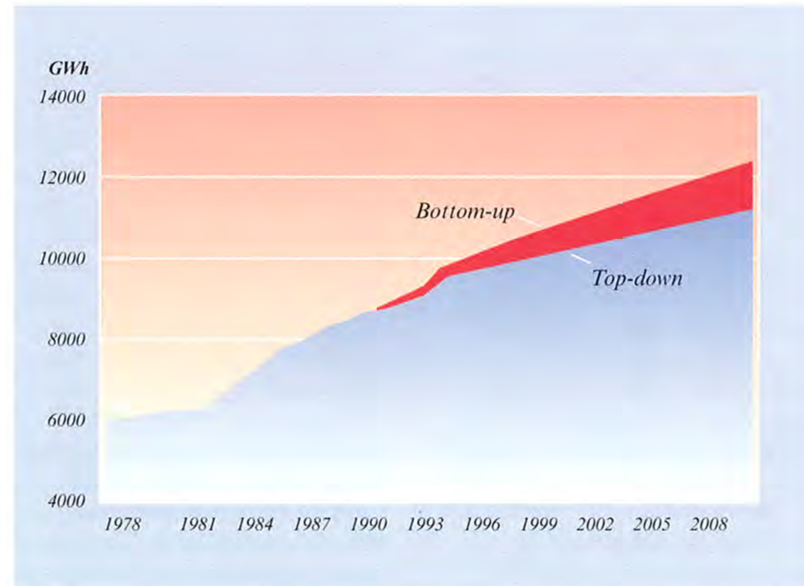



*Figure 1. Forecasts for electricity demand in the service sector using top-down and bottom-up approaches.*

*Publication in 1994: 30*

Poul Erik Morthorst

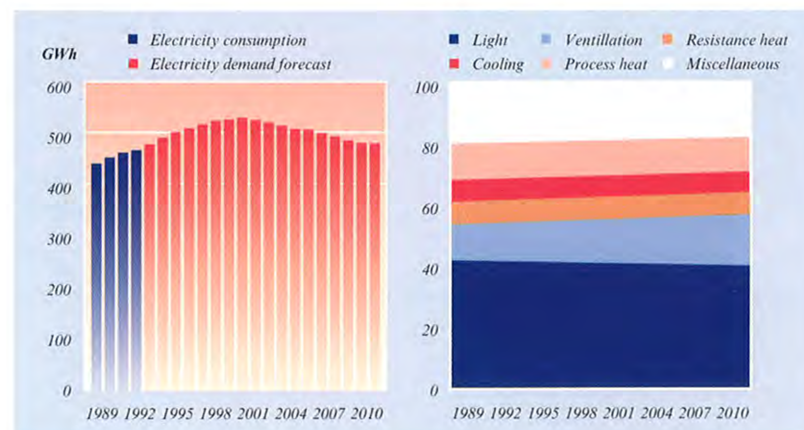



*Figure 2. Subbranch calculation. Electricity demand in "Social Institutions", split into end-uses.*

# Emission Inventories

Risø has calculated annually since 1987 the emissions of pollutants to the air from Denmark. It has participated actively in the international research in this area, and since the first publication the Danish inventory has been continually updated and refined as knowledge has multiplied. The number of pollutants covered has increased; the latest publication: "Inventory of emissions to the air from Danish sources 1972-1992" covers $SO_2$, $NO_X$, $CH_4$, $N_2O$, NMVOC, CO, ultimate $CO_2$ and at-source $CO_2$.

The at-source $CO_2$ emission is calculated by subtracting the carbon content of CO, NMVOC, $CH_4$ and particulate emissions from the ultimate $CO_2$ emission. The at-source emission is used to avoid the double counting of carbon in model calculations where all emissions are included. The difference between the two ways of accounting for $CO_2$ emissions is important only for mobile sources. The at-source $CO_2$ emission in 1992 was 1.2 million tons of $CO_2$ smaller than the ultimate emission of 60.2 million tons, e.g. there is only a difference of 2% in the total, but for the transport sector the difference was 11%.

Table 1 shows that the energy sector is the major source of the emissions except for $CH_4$ where the emissions originate from cattle (64.2%) and landfills (29.4%) and for $N_2O$, where the major source is agriculture (79.4%).

The fugitive emissions are included in the emissions from the energy sector since they all originate from non-combustion activities in this sector. The main fugitive emissions are $CH_4$ leakage's from gas networks, $CH_4$ emissions from coal storages and refineries, NMVOC from evaporations from gasoline stations and CO emissions from coal storage.

The report was issued as a background report to the report: "Climate Protection in Denmark" the National Report of the Danish Government in accordance with the United Nations Framework Convention on Climate Change. Ministry of Environment. The emission projections in the Danish country report were compiled in collaboration with the Danish Energy Agency.

In 1994 two main tasks were performed in relation to the European Union: Implementation of the FOREMOVE model in Denmark and extension of the CORINAIR inventory to include the Baltic countries.

The FOREMOVE project was financed by the Danish Environmental Protection Agency. FOREMOVE is a model which makes emission projections for road traffic. It predicts the characteristics of road traffic for the years 1990-2010. It is based on the model COPERT-90 which in great detail describes the road traffic in 1990 with respect to vehicle types, traffic volume, driving conditions, climatic conditions and fuels. With the use of a Weibull distribution of vehicle lifetime and a Gompertz function for vehicle density the future composition of the fleet is calculated. Scenarios are designed describing quantitatively the step-wise introduction of emission control, technical changes and trends for traffic developments. Emissions of ten pollutants for all years are calculated.

| % | $CO_2$ | $SO_2$ | $NO_X$ | $CH_4$ | $N_2O$ | NMVOC | CO |
|---|---|---|---|---|---|---|---|
| *Emissions from the energy sector* | 97.7 | 100 | 99.8 | 6.0 | 20.6 | 78.4 | 100 |
| *Emissions from other sectors* | 2.3 | 0. | 0.2 | 94.0 | 79.4 | 21.6 | 0 |

*Table 1. Emission from the energy sector and other sectors in Denmark*

| *kg/capita* | $SO_2$ | $NO_X$ |
|---|---|---|
| *Estonia* | 175 | 46 |
| *Latvia* | 43 | 38 |
| *Lithuania* | 60 | 43 |
| *Sweden* | 12 | 40 |
| *Norway* | 13 | 55 |
| *Denmark* | 40 | 56 |

*Table 2. Per capita emissions of $SO_2$ and $NO_X$ for 1990.*

The results of FOREMOVE will now be compared to results of the Danish model BILEMIS, which will be recalculated using the same input.

The CORINAIR 1990 inventory has now been extended to cover 31 countries, all of Europe including Russia to the Urals. Risø was project leader for the extension to the three Baltic countries Estonia, Latvia and Lithuania. The CORINAIR inventories and COPERT models are now completed for these countries. Table 2 shows the per capita emissions of $SO_2$ and $NO_X$ for the Baltic countries compared to the emission levels in the Scandinavian countries. The table show a very high emission of $SO_2$ in Estonia which originates from their oil-shale industry. The per capita emissions of $NO_X$ is at the same level as for the Scandinavian countries and in fact the rest of Europe

Ultimo 1994 the European Environment Agency has established a small number of European Topic Centres. Risø is a member of the international consortium forming the European Topic Centre on Air Emissions. The work of the Agency on air emissions will in the future be performed and co-ordinated by this centre.

*Publication in 1994: 8*

Niels A. Kilde and Jørgen Fenhann

## UNEP Collaborating Centre on energy and environment

# Incorporation of Environmental Considerations into Energy Policy

The energy related work programme of the UNEP Collaborating Centre on Energy and Environment is concentrated in two areas:

1. Assess environmental impacts of energy production and use in developing countries, and
2. Engage in energy policy studies in selected countries and formulate guidelines for incorporating environmental considerations into energy policy.

### *Environmentallly Sound Energy Development in India and China*

The UNEP Collaborating Centre on Energy and Environment provides techno-managerial support to UNEP in the execution of two national projects on energy and the environment in India and China. Environmentally Sound Energy Development – India Pilot Study was initiated in January 1992. A second study Incorporation of Environmental Considerations in Energy Policy in the People's Republic of China, similar in scale, was started in June 1993 with the signing of an agreement between UNEP and the National Environmental Protection Agency (NEPA) of the People's Republic of China.

The China and India projects are the key activities in UNEP's present energy programme. The project objectives follow UNEP's general mandate in the energy area, which is to promote integration of environmental criteria in national energy policy and planning. Specific aims are to strengthen national and regional institutional capacity in the area of energy environmental analysis and to promote policies that reduce energy-related environmental emissions.

Both projects will provide a broad overview of the respective national energy development situation and develop alternative national energy scenarios, including analysis of implementation options and establishment of a plan of action. These national activities will in part be based on more detailed case studies for selected regions and cities.

The Indian project is nearing completion and its findings will be presented to policy makers and researchers in a regional workshop to be held in New Delhi in February 1995.

To put the scope and importance of both projects in correct perspective it is necessary to re-visit the global energy future and examine the role of India and China in it. With 40% of the world's people, China and India loom large in any analysis of energy futures and their environmental impact. The World Energy Council (WEC) allocates "centrally planned Asia" (a category dominated by China) together with "South Asia" (dominated by India) a quarter of world energy consumption by 2020. In the International Energy Agency's scenario, China and India will produce a sharper increase in emissions from 1990 to 2010 than all the OECD countries combined. Between them they will emit as much as a quarter of the world's total by 2010. China plans to burn 1.4 billion tonnes of coal a year by 2000, which is equivalent to one-third of world output in 1992. The shift in global energy consumption towards the developing world demands new policies in these countries, especially in China and India.

The Indian project is no doubt poised at a very critical stage where the results will be disseminated to a wide body of people, both policy makers and other researchers. The general feedback and responses would not only help in framing policies, but also ensure that the interactive process serves as a model for factoring environmental issues in energy planning in other countries in the region. The spread and intensity of implementation of the feasible energy options taking into account the constraints and barriers to their adoption in India will determine in the long run the success of the project. In view of this long-term objective of the project, active involvement of the nodal Ministry of Environment in the study should facilitate adoption of the report by the Government of India after due review.

It is rather early in the present analytical stage of the China project to discuss specific policy issues. But what is clear is that in the next 14 months the identification of relevant energy options will be complemented by the analysis of concrete decision situations. The analysis will identify relevant decision levels and actors involved in the decision process, and specify conflicting objectives and strategies. All these factors will play a decisive role in the formulation of a long-term energy policy for China.

### *Implementation strategies to reduce environmental impacts of energy production and usage*

The Centre initiated three studies in 1993-94 in collaboration with institutions in Maharashtra (India), Zimbabwe and Sri Lanka. These studies aim at enhancing the understanding among local policy planners and researchers of implementation strategies to reduce environmental impacts of energy production and usage. The final report of the first study is now available and it identifies selected Environmentally Sound Energy Technologies (ESETs), on both the supply and demand for electrical energy, for promotion in the State of Maharashtra. The other two studies are scheduled to be completed in 1995. More details on the objectives of the studies are given below:

### *Environmentally sound energy development strategic options for the State of Maharashtra*

In addition to the broad guidelines and policies that the all India UNEP Pilot study will bring out, a detailed study of the Environmentally Sound Energy Technologies (ESETs) and preparation of a strategy for implementation of environmentally sound energy options in Maharashtra State were undertaken by the Centre in collaboration with the Indira Gandhi Institute of Development Research (IGIDR). The strategy includes a realistic action plan specific to that state, which is the appropriate administrative unit for the implementation of energy policy, especially for the electricity sector in the Indian context. The study covers the following:

- Measures for reducing auxiliary consumption in thermal power plants, an area that has not been studied systematically so far. The study indicates a substantial potential for energy savings through upgrading of auxiliaries.
- Reduction of Transmission and Distribution (T&D) losses in the Maharashtra State Electricity Board (MSEB) system. The study throws light on the possible savings at the transmission level and recommends a field study on the distribution side to identify loss reduction measures.
- Demand Side Management (DSM) options for high tension industries in Maharashtra have been identified. This part of the study is based on an earlier comprehensive investigation of DSM carried out by IGIDR for MSEB.
- Barriers in implementation, institutional and financial mechanisms required for successful implementation of suggested measures have been brought out. Actions required to be taken by various agencies have also been identified.

***Implementation strategy to reduce negative environmental impact due to energy-related activities in Zimbabwe***

The Centre's work on the Phase II of the UNEP Greenhouse Gas Abatement (GHG) Costing Studies made it abundantly clear that for most developing countries including Zimbabwe scheduling GHG abatement options is likely to follow the national agenda for development activities rather than the incremental cost curve, although the cost curve may be a good indicator of how items could be rearranged within the existing set of national priorities. The national planners would also have to consider other factors such as broader national benefits of options, and the long-term effects of these activities on social and economic factors. It may also be necessary for the country to consider its institutional capacity to implement an option or a set of options even if funding were available. The above arguments illustrate the difficulties involved in developing an abatement strategy. More importantly they provide further evidence that a country is more likely to follow its own development strategy which stresses mitigation of local pollution and environmental degradation. This may mean that in the energy sector GHG options may be adopted primarily to minimise the various negative environmental impacts of energy production and use and not only to reduce GHG emissions.

In view of the above and the interest expressed by the Zimbabwean Ministry of Transport and Energy in taking up practical measures to pursue an environmentally sound energy development strategy, the Centre decided to supplement the ongoing GHG abatement efforts in Zimbabwe by examining the issues relating to implementation strategy in greater detail. The rationale for this project is to gain experience in developing implementation strategies for environmentally sound energy plans. Due recognition must be given to the barriers that exist against adoption of efficient end-use technologies and environmentally benign supply technologies, in order to design practical policy strategies to overcome these barriers. The experience gained in developing countries shows that though efficient technologies already exist that could reduce energy use by 20-50 percent, one may not take for granted that available technology can be translated into energy savings, nor that the costs of implementing policy instruments to overcome these barriers will be negligible.

It is expected that the study will result in the preparation of an Action Plan for reducing atmospheric and local pollution caused by energy-related activities over the next ten years or so. The project will mainly focus on 'no-regrets' options' or 'low-cost' measures. The project will demonstrate a method, approach and technique of devising cost-effective implementation strategies to reduce negative environmental impacts caused by energy-related activities.

***Integrated Resource Planning in Sri Lanka***

This project was established to develop a practical approach to the implementation of Integrated Resource Planning (IRP) in developing countries through a collaboration with the Ceylon Electricity Board (CEB) of Sri Lanka. The suggested approach is to start implementation of some relatively 'easy' energy-efficiency measures (e.g., lighting), while concurrently collecting the information necessary for more ambitious demand-side management (DSM) efforts. A multi-pronged approach is used to assemble data from several sources, including

- utility load profiles and
- sector sales,
- summarising of existing energy audits,
- existing and new customer end-use surveys,
- electric equipment sales and imports, and
- technology studies.

Such data are being collected by the Sri Lanka Energy Managers Association (SLEMA) under contract to UCCEE.

UCCEE has assisted in the preparation of a DSM Action Plan for Sri Lanka, which was sponsored by the Asian Development Bank (ADB). In addition, an expected outcome of the project is useful tools for IRP, including improved end-use data and training materials based on new publications planned for 1995. Another aspect of this project is to conduct a case-study analysis of the environmental impacts of several complete fuel-cycles, using the LEAP/EDB software. This work is being done primarily by SEI-Boston, and includes LEAP/EDB training and implementation assistance in Sri Lanka from SEI.

*Publications in 1994: 39*

PRAMOD DEO





Many developing countries are now investigating what climate change means for them: both how climate change might affect their environment, agriculture and economy, and how they can contribute to global efforts to minimise the causes of climate change. Several such country studies are being carried out by African countries in collaboration with UCCEE, and indeed some have already completed significant parts of their investigations. In addition, UCCEE is collaborating in the development of an action plan on climate change mitigation in Costa Rica.

The UNEP Greenhouse Gas (GHG) Abatement Costing Studies included African country studies in Egypt, Senegal and Zimbabwe among the ten participating countries. Subsequently, three new activities have been initiated in Africa – a regional study embracing four countries in southern and eastern Africa, a project on capacity building and the GHG inventories in the republic of Burkina Faso, and technical back-up to a mitigation study in Tanzania.

***Climate Change Mitigation in Southern Africa***

The project initiated by UCCEE, in collaboration with institutions in Botswana, Tanzania, Zambia and Zimbabwe, deals with subregional mitigation analysis and national strategy development in Southern Africa. It aims to:

- develop and test a methodological framework for subregional mitigation analysis and strengthen the regional approach and responses to the issue of climate change;
- establish national frameworks for mitigation strategies in the four participating Southern African Development Community (SADC) countries in line with general development objectives; and
- establish or improve the national capacity to comply with the requirements of Framework Convention on Climate Change.

This regional approach intends both to build national capacity through collaboration between local teams and to analyse the regional implications of major abatement options implemented either in individual countries or in all countries of the region. These may include technical options related to specific sectors (energy, forestry, agriculture, industry or transport) or policy instruments like taxes, financial schemes and investment grants.

The project, supported by DANIDA, is managed and co-ordinated by the UNEP Centre and will build upon the experience accumulated through the UNEP GHG Abatement Costing Studies, especially the work in Zimbabwe, which will provide a model for work in the other countries. UCCEE will be responsible for developing the regional methodological framework on the basis of existing guidelines for national GHG abatement costing. In the four countries involved in the project, relevant ministries are formally responsible for the activity. In each case a local institution or non-government organisation (NGO) is responsible for performing the actual analysis.

***Climate Change Effects in Burkina Faso***

Following the entry into force of the climate convention, the Government of Burkina Faso has

requested the Danish Government to provide technical assistance and support in order to assess national contributions to global GHG accumulation and to identify the most relevant GHG abatement options for national target-setting and action.

In reply to this request, UCCEE has been commissioned by the Danish Ministry of Foreign Affairs to undertake a collaborative project with the objective of assisting the Government of Burkina Faso in building sufficient indigenous institutional capability to establish the initial reporting to the Framework Convention on Climate Change (FCCC), to periodically carry out national inventories on anthropogenic GHG emissions, and to pursue policies and actions that would enable the country to cope with the negative impacts stemming from climate change. The project aims to:

- develop a reliable data base on anthropogenic sources and sinks of GHG emissions with special emphasis on deforestation, power generation, energy use and land use;
- provide the National Committee on Climate Change with the necessary analytical framework to carry out periodical GHG inventories and mitigation scenarios; and
- examine natural vulnerability and possible adaptation strategies to climate change.

A preliminary analysis suggests that forestry mitigation options aimed at reducing the atmospheric accumulation of GHG either by maintaining existing stocks (forest protection and conservation, forest management, increased efficiency in biomass uses) and/or by expanding carbon sinks (afforestation, reforestation) will have a direct positive impact on the country's social and economic development. Therefore, in the case of Burkina Faso, responses to issues of climate change can generate a wide range of benefits at the national and local levels which could be, in the short term, even more important to the country's development than the effects of GHG reduction, so that the "economic and environmental double dividend" represents a sufficient reason to undertake a GHG mitigation strategy.

### *Mitigation Options in Tanzania*

A country study on climate change mitigation options is being undertaken by the Department of Environment of the Ministry of Tourism, Natural Resources and Environment in collaboration with the Centre for Energy, Environment, Science and Technology (CEEST) in Dar es Salaam. The study, managed and technically co-ordinated by the CEEST is funded by the German Agency for Development Cooperation (GTZ) and the UNEP Centre has been engaged to provide advisory and technical back-up.

UCCEE collaboration in the study is focused on providing CEEST with methodological guidance, analytical approaches and concepts along with recent relevant literature on the key issues of mitigation analysis. The methodological guidelines develop by the Centre in the context of the UNEP project on GHG abatement costing studies will serve as a framework to gain insights and a better understanding of the implications of different mitigation strategies on the country's social and economic development. This collaborative effort between CEEST and UCCEE also aims at integrating the national mitigation analysis into the perspective of the SADC subregional study.

### *Costa Rica's Action Plan for Climate Change*

The Costa Rican government is in the early stages of developing a plan for a "transition to sustainability." This plan is being designed for implementation during the next four years, with the long-term goal of achieving a sustainable course of development, an efficient, renewable-energy-based system and land-use management that provides for sustainable production of agricultural goods and biomass energy as well as net carbon accumulation.

A major aspect of the design of this plan is the development of an Action Plan for Climate Change, which pursues the ambitious goal of making Costa Rica a net sink of atmospheric carbon. Costa Rica is well endowed with a high level of professional expertise in many of the relevant technical fields, especially tropical biology, but outside collaboration is needed to ensure that state-of-the-art energy analysis and planning methods are applied to this effort.

At the request of the Costa Rica Ministry of Natural Resources, Energy and Mines (MIRENEM), UCCEE is collaborating with MIRENEM and other Costa Rican institutions in the development of the following aspects of the Action Plan for Climate Change:

- review of the National Energy Plan to incorporate climate change objectives;
- linking land-use capacity and emission models to identify carbon storage potential; and
- design of a national portfolio of climate change mitigation projects and programmes.

After a preliminary visit to Costa Rica in August 1994, UCCEE made recommendations to MIRENEM regarding the following needs for near-term activities:

- extend the present work on national emission inventories to establish emission scenarios and a framework for baseline cases, for individual technologies at the national level;
- establish a framework for project evaluation and emission reduction and carbon storage credits in energy and forestry, based on existing evaluation methods and models;
- establish a governmental body to create and house a mitigation project registry and approval procedure;
- elaborate Costa Rica's domestic requirements for foreign investment in measures to reduce greenhouse gas emissions and increase sinks, including reduced local pollution, increased energy security, sustainable land-use practices, improved rural incomes, etc;
- establish a framework for project monitoring and verification in energy and forestry;
- set up a consultative process to collect proposals for the project registry and other project identification information and analytic tools for incorporation into a national portfolio;
- screen methods for project evaluation, verification and baselines, in order to begin a process of standardization and certification of evaluation and verification methods;
- design the financial aspects of the portfolio, which would pool different projects for the purposes of sharing and insuring risk, and also average out costs; and
- examine natural vulnerability and possible adaptation strategies to climate change.

Through collaboration in the development of this plan, UCCEE expects to begin a long-term collaboration with MIRENEM. This pioneering effort in Costa Rica is expected to lead to regional collaborations with institutions in other countries in Central America.

*Publications in 1994: 38 and 55*

JOEL SWISHER

The second phase of the UNEP Greenhouse Gas Abatement Costing Studies was finalised in 1994 with the publication of general conclusions on the methodological framework and national cost assessments.

The study developed and applied a consistent set of guidelines for making national analysis and conducting country studies for: Brazil, Egypt, India, Senegal, Thailand, Venezuela, Zimbabwe, Denmark, France and The Netherlands. The country studies followed a common analytical structure with the central features: definition of reference scenario, identification of abatement options and construction of a consistent abatement scenario. These studies aimed at attaining specific values of emission reduction in a defined short term 2005/10 and in the long term 2020/30. The common analytical structure of the country studies is shown in figure 1.

***General conclusion on abatement costs across countries***

Country teams estimated abatement costs for reduction targets of 12.5 to 25 percent reduction from reference scenario in the short term and 25-50 percent in the long term. These costs are measured as the direct/financial cost at energy system level including: levelised investment, operation- and maintenance cost and fuel costs.

The country cost curves show some similarities. In the short term 10-15 percent $CO_2$ reduction can be achieved for a negative or low marginal reduction cost, followed by an interval covering up to about 25 percent reduction, where costs still are lower than US$ 30 per tonne $CO_2$ reduced. The costs fall in the long term within an interval of – US$ 10 to US$ 25 per tonne $CO_2$ reduced for a broad interval of emission reduction from about 10 to 40 percent reductions.

The main reason for a larger and cheaper reduction interval in the long term is that the opportunities for capital replacement increase over time allowing more $CO_2$ - efficient technologies to be implemented.

Another important similarity between the country studies is that the least expensive part of the cost curve contains energy end-use savings in households and/or industry. A common result is also that electricity supply options first appear in the final portion of the reduction potential on the cost curves.

***Comparability of abatement cost assessments***

Attaining comparability has been a main aim in the country studies because it enables the cost assessments to be used as inputs in the context of resource transfers, such as appear under the Climate Convention.

In a context of significant abatement related to projected future emissions, national development plans become important, and the idea of comparability becomes complex and multifaceted. No two countries have identical energy system structure and consequently identical abatement possibilities. Neither is it likely that two countries will have identical expectations for technical performance of abatement options. It must therefore be accepted that different national conditions and predispositions are legitimate reasons for different choices of technologies.

The implications on the assessed cost and abatement potential of different national priorities and expectations on technological development can be further understood through a more detailed examination of the individual national cost curves.

Figure 2 focuses on the Zimbabwean cost curve with the other national cost curves shown in the background. Zimbabwe has estimated a long interval of emission reductions up to about 35% and reduction cost are very low. The technical options are here end-use efficiency improvements in industry and the introduction of hydroelectricity to substitute for power production by local coal resources. After this interval the marginal reduction cost increases very steeply. This is a a consequence of limited detail in the more expensive technical options covered in the analysis.

The Egypt cost curve shown in figure 3 illlustrates a situation with a large number off technical abatement options in the analysis. A total of 57 abatement options are included, giving a potential of 52% $CO_2$ reductions in 2020/30 with a cost below US$ 7 per tonne of $CO_2$. Energy efficiency improvements in industry and the transportation sector are especially recommended. The critical question is: how can such efficiency improvements be implemented. This is now being investigated further by the Egyptian team.

The examples of Zimbabwe and Egypt illustrate that a comparison of national abatement costing studies requires extensive documentation on economic and technical assumptions. In this way comparability in the UNEP study has become a combination of transparency, uniform analytical approaches and assumptions, as well as the ability to understand and explain differences between national abatement strategies and costs.

***New sectors and options***

The UNEP methodological framework and country studies are now being developed further in a third phase involving two countries. The methodological aim is to expand the assessment from the phase two focus on energy and $CO_2$ emissions to cover other greenhouse gasses and reduction options in agriculture, forestry and waste management.

*Figure 1. Common analytical structure of the country studies.*

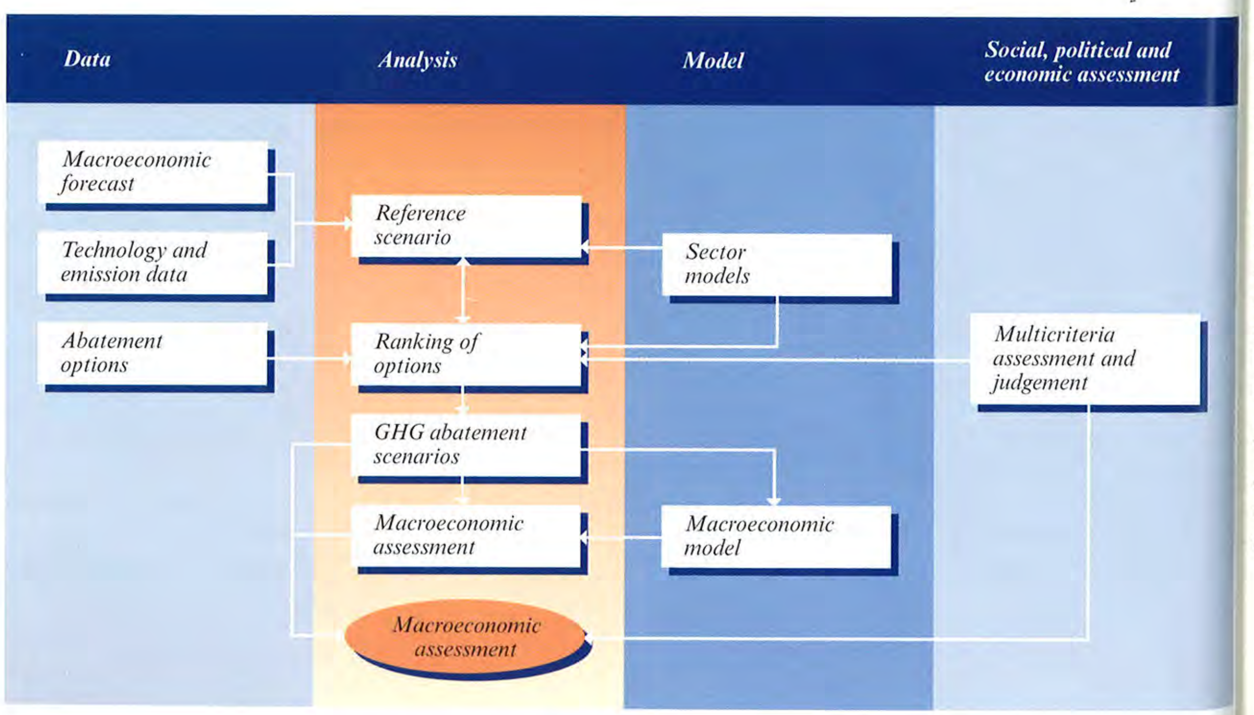
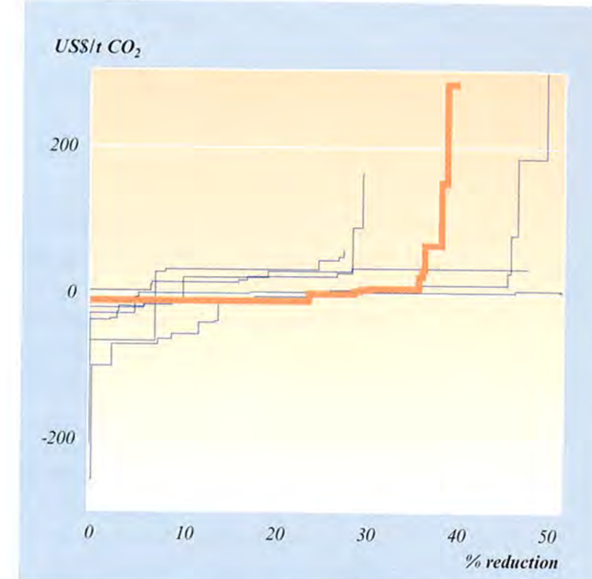



*Figure 2. Zimbabwean cost curve.*



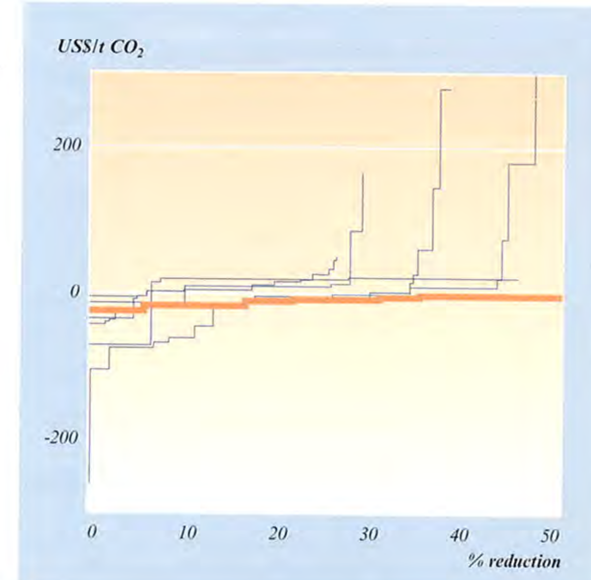




*Figure 3. Egyptian cost curve.*

Country studies are carried out for Zimbabwe and Venezuela in collaboration with Lawrence Berkely Laboratory, US.

*Publications in 1994: 14, 15, 52, 53 and 54*

Kirsten Halsnæs

# The Second IPCC Assessment

## Economic and Social Issues Related to Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is currently reviewing the state of scientific information on climate change and the greenhouse effect, and expanding and updating this information where necessary in order to establish a comprehensive and operational knowledge base on the subject for policymakers and non-specialists. This is particularly important as we enter the next, implementation phase of the Framework Convention on Climate Change (FCCC) following the first Conference of Parties in 1995. A second assessment report is being prepared for government approval in September 1995.

In addition to the issues examined in the first assessment, the second IPCC assessment will include a comprehensive evaluation of economic and social issues. These issues are covered by Working Groups II and III and are expected to provide important new information on global economic and equity aspects related to the FCCC. This includes consideration of the costs and benefits of climate change, and of the costs of adaptation and mitigation strategies.

UCCEE participates in the writing process of Working Group III, with Kirsten Halsnæs as principal lead author on the chapters on mitigation cost assessment, methodologies and study results. This work has concentrated particularly on a review of methodologies and studies for developing countries. This study represents the first comprehensive assessment and comparison of mitigation analysis for developing countries.

The IPCC reviews two major bottom-up multi-country studies for developing countries done by the Lawrence Berkeley Laboratory (LBL) and by the UCC. The results and methodological framework of the two multi-country studies are reviewed along with similar country studies for China, West Africa and Southeast Asia. The review includes 23 studies in all.

### *Conclusions on the mitigation costing studies*

A common conclusion from these 23 studies for developing countries is that energy requirements will increase in the future due to current low consumption levels in the reference scenarios, however the energy intensity of Gross Domestic Product will be decreasing. The decreasing energy intensity is a reflection of study assumptions on a large potential for energy efficiency improvements and technological development in the developing countries. The $CO_2$/energy intensity is in contrast expected to increase. This reflects a development process in which traditional biomass and also hydropower resources are expected to have a decreasing share of future primary energy consumption while the use of fossil fuels is increased.

The studies considered exhibit similarities with regard to the assessed potential for negative or low-cost emission reductions. In general these options comprise end-use efficiency improvements, energy supply efficiency improvements and the introduction of fuels with lower carbon intensity. The implementation of such technologies will lead to 30-40% emission reduction over a 40 year time frame with negative or low reduction costs.

But even after the implementation of these 30-40% emission reductions, the $CO_2$ emissions of the developing countries under consideration will increase two to three times from current levels due to the energy requirements related to their expected economic growth.

### *Assessment of methodologies for cost assessment*

Working Group II addresses the methods for the assessment of mitigation options. This includes an outline of a framework comprising a common analytical structure and methodology for mitigation studies. The second assessment will include a report on these issues on the basis of extensive review by experts in the field. As part of the review activity, UCCEE hosted a workshop in Copenhagen on 6 June 1994 where a group of experts from developing countries and OECD countries participated. John Christensen from UCCEE is one of the lead authors of the subchapter.

### *Methodological requirements*

The UNEP GHG Abatement Costing Study has been instrumental in expanding the coverage of mitigation assessment studies to developing countries, both in terms of developing the methodology and in building local capacity. But the development of methodologies and models for mitigation assessment seen from the developing country point of view is however still at an early stage. This is an unavoidable consequence of the focus in international research on the economics of climate change that has been undertaken until now.

One of the important observations made by the lead authors from developing countries is that the social and economic issues facing different developing countries are more diverse than is the case for OECD countries. Countries may face different issues as a consequence of their general development situation, because of the greater vulnerability of many developing countries to climate change effects, and due to the consequences of implementing mitigation measures. If this observation is confirmed then there is a good case for developing improved understanding in these areas, and this will require further studies on methodologies and options for developing countries and regions.

Kirsten Halsnæs

# Toxic Hazards from Pesticide Warehouse Fires

A large number of chemical plants and warehouses are in operation in most countries. They handle and store substantial amounts of hazardous substances, e.g. pesticides. Chemical fire is one of the most important hazards related to these storages.

A number of fires have actually occurred at some of these chemical installations. Large quantities of chemicals have been involved with the formation of significant amounts of toxic fire effluents. It is likely that some of these products been dispersed with the fire plume, thereby threatening or actually causing harm to humans that had been working at the chemical store, staying in the vicinity or taking part in the fire fighting. Also, the environmental consequences to soil, groundwater, rivers etc. from release of contaminated fire fighting water and deposition of soot particles proved to be problems in some fires.

In 1994 work has been carried out as part of EU projects. These projects have been in progress for some years. Methods have been developed to predict the chemical composition of the fire plume and assess the toxicological consequences to humans from chemical warehouse fires. The work comprised DIN 53 436 (Deutsche Normen, 1981) combustion experiments involving various pesticides. Identification and quantification of the fire products were carried out by means of the FTIR gas analysis technique, and methods for predicting the toxic compounds that could be generated were established. An N-gas model was applied for evaluating the toxicity of the complex mixture of fire effluents from the compounds investigated. The present paper deals particularly with the assessment of the toxicity of the fire effluents.

### *N-gas Models*

A number of models have been developed for predicting the toxicity of fire effluents. Based on concentration data for the individual components in the fire effluent and the toxicity data for these gases the toxic effects can be predicted. The models are based on the assumption that the toxic effects of the individual components are additive and that a limited number of major components in the fire effluent are responsible for the toxicity.

A major advantage of the use of such models is that the number of animal experiments can be limited or even avoided. However, it should be stated that the calculated toxicity values can be used only for screening purposes, providing indicators of the "toxicity level" of the fire effluents or a rough comparison of the toxic fire hazards from the individual compounds. Direct use of the calculated values should be avoided or treated with special care.

An empirical N-gas toxicity model developed by NIST was used as a basis in the present work (Babrauskas et al., 1991). The model takes narcotic as well as irritant gases into account. The FED (Fractional effective Exposure Dose) is expressed as shown in the top of the next page.





$$\mathrm{FED} = \frac{m\,[CO]}{[CO_2]-b} + \frac{[HCN]}{LC_{50}(HCN)} + \frac{21-[O_2]}{21-LC_{50}(O_2)} + \frac{[HCl]}{LC_{50}(HCl)} + \frac{[HBr]}{LC_{50}(HBr)}$$

The first term of the equation expresses the potentiation of CO by $CO_2$. m and b are constants that depend on the $CO_2$ concentration. The third term of the equation reflects the "toxic effects" which are seen if the oxygen concentration is decreased. All values are in ppm except the $O_2$ concentration, which is in %. The model is based on a 30-min. exposure of rats plus 14-day post-exposure. By definition a FED = 1 corresponds to a 50% lethality, but due to small nonlinearities, the 50% lethality is denoted by a FED = 1.1 (95% confidence interval of ±0.2).

The following $LC_{50}$-values for the individual combustion gases are recommended in the NIST report:

$LC_{50}$ ($O_2$) = 5.4 %;
$LC_{50}$ (HCN) = 150 ppm;
$LC_{50}$ (HCl) = 3800 ppm
$LC_{50}$ (HBr) = 3000 ppm.

### *Modification of the NIST N-gas Model*

Additional contributions had to be included in the model in the present work, since other gases were also generated in significant amounts. Purser (1993) suggests the following values:

$LC_{50}$ ($NO_2$) = 170 ppm;
$LC_{50}$ ($SO_2$) = 400 ppm.

Identical values for $NO_2$ and $SO_2$ are also included in ISO/DIS 13344 (1994). This proposal includes also:

$LC_{50}$ (Acrolein) = 150 ppm;
$LC_{50}$ (Formaldehyde) = 750 ppm.

Additional $LC_{50}$-values had also to be included. These data have been found by inspection of the RTECS database:

$LC_{50}$ ($NH_3$) = 3000 ppm;
$LC_{50}$ (NO) = 7000 ppm;
$LC_{50}$ ($COCl_2$) = 350 ppm;
$LC_{50}$ ($CS_2$) = 4000 ppm;
$LC_{50}$ (COS) = 1200 ppm;
$LC_{50}$ ($H_2S$) = 1000 ppm.

All $LC_{50}$-values are derived from animal (rat) inhalation studies. No efforts have been made to carry out a comprehensive analysis of the toxicity data, so future corrections of the values might be needed.

The effects of the fraction of the original chemical which survives the combustion process and is entrained in the fire plume should be taken into account, particularly in the case of a pesticide fire due to the high toxicity of some of these compounds. Only very limited information on the survival fractions of pesticides is available. The Green Book (CPR 16E, 1992) suggests that from 1-2% to 10% of the pesticide will survive the combustion process. Based on a limited number of medium-scale experiments Molag, Bartelds & de Weger (1992) suggest that a conservative estimate is that 0.57% of the pesticide is entrained in the fire plume. Atkinson & Jagger (1992; 1994) report that survival fractions could be as high as 10% under certain conditions for the three pesticides tested in their study. They observed the highest values when the pesticide was subjected

*Fire at the Swiss chemical plant Sandoz in 1986.*

to diffusion flames. Under ventilation-controlled conditions the survival fractions were much lower. In the present work survival fractions of 0.1%, 1% and 10% have been used.

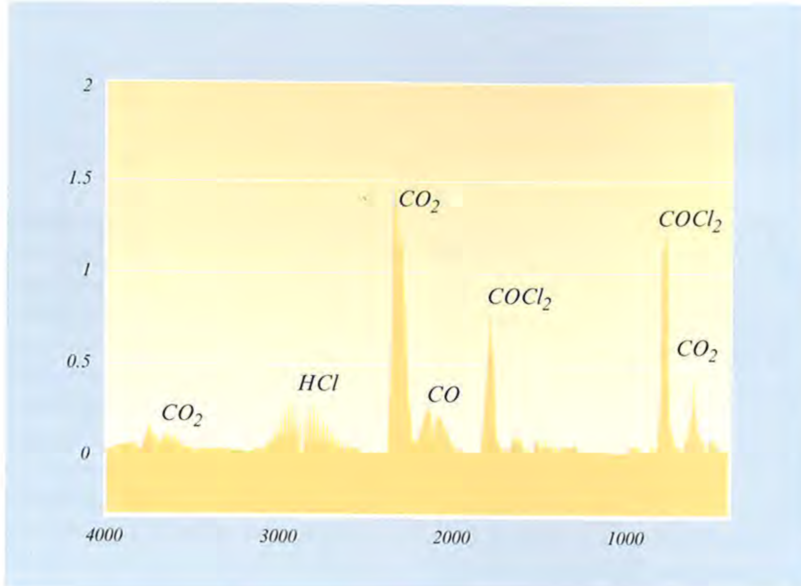
***Problems***

It should, however, be noted that the results of the estimates of the FED values described above might be misleading for some substances. The effects of the individual toxicants are assumed to be additive, but this is not necessarily the case. It is also known that HCl concentrations below 1000 ppm might not have any lethal effects at all; $NO_2$ and $CO_2$ show synergistic effects and $NO_2$ combined with HCN show antagonistic effects; HCN potentiates the toxicity of CO (Babrauskas et al, 1991). Furthermore, the effects of the organic decomposition products are not included. In addition, long-term effects cannot be evaluated by the model. Finally, it should be remembered that the model is basically derived from animal inhalation studies. The prediction of toxicity in humans from animal toxicity data is not an easy task.

***$LC_{50}$-values***

The purpose of the N-gas model is to estimate an acute $LC_{50}$-value for a substance subjected to combustion. FED values depend on the dilution of the combustion gases, but this is not the case for $LC_{50}$-values. The $LC_{50}$-value is defined as the mass of material lost during combustion per unit air volume in which smoke gases are diluted causing 50% mortality of the population following an exposure of 30-min. and 14-day post-exposure. $LC_{50}$-values are calculated as follows:

*FTIR spectrum of toxic fire plume.*




$$LC_{50} = \frac{\Delta m}{FED \cdot V}$$

$LC_{50}$ is in g/m³, V is the total air volume per time unit in m³, and $\Delta$m is the mass loss in gram per time unit.

***Results***

Below follows an example of how the $LC_{50}$-values are determined. The values were calculated by means of the N-gas model described above. The DIN 53 436 experiments were carried out with different sample loads in order to investigate the effects of that parameter.

| Sample load (g) | Survival fraction 0.1% $LC_{50}$ g/m³ | 1% $LC_{50}$ g/m³ | 10% $LC_{50}$ g/m³ |
|---|---|---|---|
| 3 | <6.8 | <6.5 | 4.4 |
| 2 | 6.4 | 6.1 | 4.2 |
| 1 | 4.8 | 4.6 | 3.4 |

*Table 1. $LC_{50}$-values for combustion of lindane.*

It can be concluded that the sample load has a certain effect on the toxicity of the fire effluents. The survival fraction has also some effect. However, lindane is not one of the most toxic pesticides, and therefore the influence from the survival fraction of the pesticide is not as significant as for some of the organophosphorous insecticides.

*Publications in 1994: 106, 107, 108, 109 and 110*

LENE SMITH-HANSEN





# RELIABILITY ASSESSMENT OF ROBOTS FOR RADIATION APPLICATIONS

Under the EC's TELEMAN programme the Risk Analysis Group (RAG) has performed a number of reliability analyses of robots intended for use in areas with high levels of radiation, e.g. in reprocessing plants or following an accident in a nuclear facility. Such robots must have a high reliability in order for them to perform their tasks correctly and not break down in a place from which they cannot be retrieved. The TELEMAN programme has supported the development of a number of different types of robot as well as special equipment for use in the operations and environment foreseen for such robots. The Risk Analysis Group has taken an active part in four of the 21 TELEMAN projects, with the main effort on ENTOREL (ENvironmental TOlerance, RELiability and safety), which we coordinate. This project has as its task the study of problems relevant to the various TELEMAN machines within the subject areas of radiation tolerance and reliability and safety. Our partners in this project are AEA Technology – Harwell Laboratory (UK), Siemens Energieerzeugung KWU (Germany) and SCK·CEN, Mol (Belgium). In addition to running ENTOREL, RAG has taken part in three other projects in 1994 with the specific task of carrying out reliability analyses of the designs in question. One of these designs is a gantry-type robot and the other two were a gripper designed by a team led by the Technical University of Delft (NL) and a small mobile robot, ROBUG III, being constructed under the leadership of Portech (UK).

The participation in the TELEMAN projects has given us an opportunity to test our tools for reliability analysis and develop them further in order to be able to address the special problems arising when an aggressive environmental factor, such as radiation, is affecting the reliability of the equipment considered. The various systems considered, of course, have had many similarities, but they have also been sufficiently different to allow us to try out different approaches to the analyses.

The ROBUG III machine is an eight-legged crab-like device with sucker pads as feet, enabling it to climb walls and walk on ceilings. It is being developed with a view to inspection-, maintenance- and repair tasks in areas with restricted space and difficult access. The robot contains many electronic and other components sensitive to radiation damage. Therefore, the analysis has focused upon identifying the failure possibilities which are caused by this sensitivity, and to quantify the expected time of operation before radiation has made the robot inoperable. But, due to the large number of components in the machine, it has proven relevant also to consider the "traditional" reliability, i.e. the reliability that is a function of failures occurring in the components stochastically.

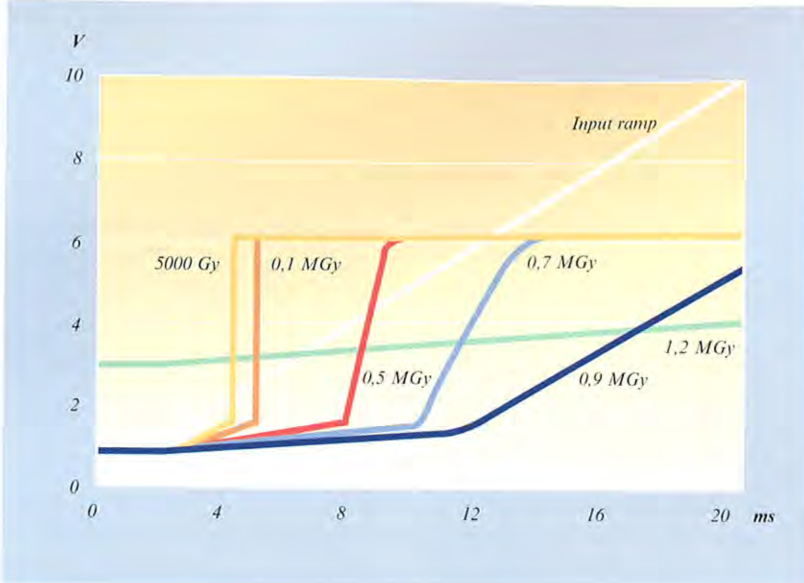
The failure behaviour of the entire robot system was modelled, based on the technical documentation available and frequent communication with the design team. A reliability model expresses the way failures in single components can lead to failures in the subsystems and, eventually, the whole robot. The model is most often visualized by means of fault trees.

The fundamental input is given in a so-called nodal input file. It is processed by a program that prepares input for the fault tree analysis programs FAUNET, which is based on cut sets, and for SIMON which is a Monte Carlo simulation program. The reliability data for each basic event can be entered manually or – by means of a computer program – taken from a data document, written by means of a normal word processor and containing a descriptive text and references to the origin of the data in addition to the reliability data. FAUNET and SIMON basically calculate the same reliability characteristics; they supplement each

*By courtesy of Portech Ltd.*

other in the sense that FAUNET normally is faster than SIMON, but SIMON is able to handle more complex events than is FAUNET.

The model for ROBUG III comprises the robot itself and the control station, which is outside of the radiation field. The two are connected by an umbilical carrying signal wires, power cables and




*Simulated output voltage of a radiation tolerant Schmitt trigger for different doses of γ-radiation*

a hose for pressurized air. The robot model consists of a large number of components, e.g. microcontrollers, valves, pneumatic hoses, cameras, gyros, inclinometers, mechanical links of the legs and lots of wiring.

The reliability model, in principle, describes every possible way for the robot to fail partially or totally. But only a limited number of these ways are of interest in a general analysis like this one. These top events, which were selected in agreement with the designers of the machine, are:

- Loss of communication with the robot
- Loss of control with more than 3 legs (max. 2 legs on the same side of the robot)
- Loss of power (electrical and/or pneumatic)

These three events all will cause a – more or less definitive – loss of the robot and, therefore, must be avoided to the greatest extent possible.

For each of the top events above calculations were made, resulting in lists of "cut sets", i.e. single component failures or combinations of failures that will lead to the top event in question. The cut sets appear in order of importance in the lists, thus highlighting areas where improvements in the design might be needed. These cut set evaluations were carried out separately for the "traditional" reliability and the radiation degradation.

In order to produce the above mentioned ordered cut set listings, reliability data and radiation degradation data had to be elicited. Since ROBUG III is a prototype containing many prototypic components, statistical reliability data for these components do not exist and "engineering judgement" had to be applied. Data for other components which are standard or close to it could be found in the reliability literature; this was the case for most of the electronic components.

The quantification of the radiation sensitivity was carried out using a method developed for the purpose of TELEMAN. Instead of entering the usual failure rate data in the reliability model, radiation degradation factors for the components were entered. The radiation degradation factor of a component, Δ, is defined as shown below.

Similar to the usual failure probabilities, Δ will lie in the interval [0;1].

The parameter values were estimated for the relevant components and subsystems from radiation degradation functions describing how the particular material or type of component changes its properties as the radiation dose increases. These functions, in turn, were specified on the basis of documentation available from the ENTOREL project and other sources.

The reliability of the central electronic component, a microcontroller card, was analysed in particular detail because of its vital importance to the functioning of the machine and also because it is used in several places. This analysis was carried out by means of a PC program, RDF93, tailored for reliability analyses of electronic circuits.

The results of the analyses are presented to the design team in the form of fault trees, illustrating the model, and cut set listings, quantifying the probability of occurrence of the selected top events during an operation and the importance of the different components of the machine in this respect. Thus, the analyses can form the basis for possible changes in design and operational procedures. as well as for the planning of the maintenance of the robot.

The results show that the conventional reliability of the robot is good, whereas the radiation tolerance of the machine – with the components chosen – is not sufficient to ascertain that it will survive the design dose of 1000 Gy.

$$\Delta = \begin{cases} (P_0 - P_t)/(P_0 - P_f) & \text{for } P_0 \geq P_t > P_f \text{ or } P_0 \leq P_t < P_f \\ 0 & \text{for } P_t > P_0 > P_f \text{ or } P_t < P_0 < P_f \\ 1 & \text{for } P_0 > P_f > P_t \text{ or } P_0 < P_f < P_t \end{cases}$$

where

*$P_0$ = Value of a characteristic parameter (e.g. the modulus of elasticity of a polymer) before exposure.*

*$P_t$ = Value of the characteristic parameter after a total radiation dose $D_t$.*

*$P_f$ = Value of the characteristic parameter at failure.*





However, improvements can be made by replacing some components by radiation-tolerant versions, using the cut set lists to identify which ones are to be exchanged.

For TELEMAN robots in general electronic semiconductor components are the parts most vulnerable to irradiation. Therefore, it is important to be able to predict the performance under irradiation of circuits containing these types of component. We have studied this subject by means of the PSpice simulator program by introducing expressions for component parameters as functions of radiation dose. We have carried out simulations of a few small circuits such as a Schmitt trigger with discrete components and a couple of types of flip-flops based on CMOS integrated circuits. The method has been successfully validated by comparison with experimental results. Thus, it seems to be applicable for estimating the useful lifetime of electronic circuits under irradiation.

Although the TELEMAN analyses focus very much on the effect of ionizing radiation on the behaviour of the robots, we consider the methods applied to have a wider potential. They are relevant also for other areas where a particular environmental factor may be important for the safe functioning of mechanical and electronic equipment. Therefore, it is intended to carry on the development of the methods, in particular to devise ways of incorporating the environmental effects data into the reliability data in a more formal manner. For this purpose both a fuzzy–set approach and an approach using the Bayesian method are being investigated.

*Publications in 1994: 68, 81 and 82*

KURT LAURIDSEN,
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# HAZARD IDENTIFICATION BASED ON PLANT FUNCTIONAL MODELLING

A crucial part of any safety analysis of a process plant is the identification of hazards which may be carried out either at unit or plant level. Appropriate methods exist for hazard identification at unit level, e.g. HAZOP. However, for large process plants the effort required can be excessive, making it very difficult to establish a risk survey for the entire plant. Furthermore, the emphasis of these methods is on the identification of hazards closely related to the plant hardware and less on hazards related to the interaction between the plant equipment, control systems, operators, organisational systems and management.

The major objective of the present work is to provide means for representing a plant as a socio-technical system, so as to allow hazard identification at a high level in order to identify critical areas. The work is part of the project *An Overall Knowledge-based Methodology for Hazard Identification* (working title: TOMHID) sponsored by the EC STEP programme carried out by an international consortium consisting of VTT (Technical Research Centre of Finland), The University of Sheffield (UK), SRD Division of AEA Consulting (UK), TRI (Italy), JRC-Ispra (Italy), CIEMAT (Spain) and Risø National Laboratory (Denmark).

The project was initiated in 1991 and finalized in 1994. The main Risø contributions have been concentrated on the development of a plant functional model and the link between the plant functional model and the event sequences leading to incidents. During 1994 the emphasis has been laid on the development of a method for investigating the impact of management on the causes and consequences of specific hazards.

### *Principles of functional modelling*

The basic idea is that a set of plant functions links together hardware, software, operations, work organisation and general management aspects of the plant. The principle of functional modelling is that any aspect of the plant can be represented by an object based upon an Intent and associated with each Intent are Methods, Constraints, Inputs and Outputs. The elements are presented in Figure 1 and can be classified as follows:

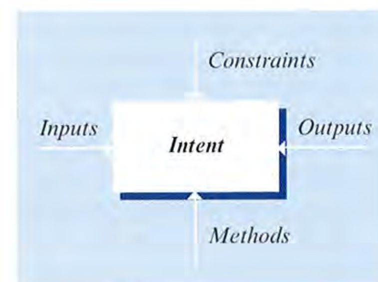



*Figure 1. Functional modelling principle.*

- The *Intent* represents the functional goal of the specific activity in question.
- *Methods* representing items (hardware, procedures, operations etc.) necessary for performing the Intent, but which are not changed or consumed in it.

- *Constraints* representing items (physical laws, work organization, control and protective systems etc.) that exist to supervise or restrict the Intent.
- *Inputs* are the necessary conditions to perform the Intent and the link to the previous Intent. Inputs can be either transformed or used during the performance of the Intent in order to produce the Outputs.
- *Outputs* show the outcome produced by the Intent and the link to the subsequent Intent. Outputs can include desired products, by-products, waste products and unwanted outcomes.

The Methods and Constraints can themselves be treated as objects and decomposed into lower-level Intents (hence the procedure is known as functional decomposition), in this way giving rise to a hierarchical structure. The functional decomposition is continued and refined at the subsequent levels until an appropriate level of details has been achieved. Figure 2 presents an example of a functional description. The function "Provide chemical XYZ" is decomposed to its lower level intents.

***Plant level hazard identification***

In the first step of the hazard identification process, Concept Hazard Analysis (CHA) is used to identify the main hazards the process plant might generate or face. CHA utilises a set of keywords which are applied on the functional blocks described in the model.

***The impact of management on causes and consequences of specific hazards***

Based on the functional model and the CHA it is possible to identify hazardous conditions or dangerous disturbances, but the event sequences leading to the incidents will not necessarily appear from the plant functional model and the CHA.

In the next steps of the hazard identification process the impact of management on causes and consequences of the identified hazards are investigated. First, a number of hazardous situations are selected with different critical safety characteristics (severity, plant function/activity/location, hazard category). For these hazards incident scenarios are developed which can lead to the identified hazards, and furthermore an extended plant functional model including work organization and management factors is prepared on these parts of the plant. It is anticipated that, for plant level hazard identification purposes, 5-10 incident scenarios will be sufficient to cover the most essential safety aspects.

The impact of human and management factors on plant safety is evaluated through interviews. The detailed plant functional model and the incident scenarios form the basis for the management analysis structured as follows:

- *Worker interviews*: The workers who could be involved in the incident scenarios are named, and the error- and violation-producing conditions are identified and discussed.
- *Management interviews:* The managerial tasks related to the conditions discussed during the worker interviews are identified. The characteristics of the organisational processes which propose error- and violation-producing conditions are examined by interviewing the people involved in the managerial tasks.
- *Group working session:* The problems are evaluated and proposals for improvements and corrective actions are developed and ranked during a group working session.
- *Use of results:* Finally, it is discussed how to implement the proposed preventive and protective safety measures.

***Experiences from case studies***

The applicability of the methodology has been evaluated by performance of case studies, batch as well as continuous process plants. The experiences can be summarised in terms of:

The *functional model*, proved useful in concentrating and integrating information from flow sheets, PIDS and other plant documents. The functional description enables the integration of different types of information necessary for hazard identification.

"Methods" and "Constraints" identified as hardware (e.g. equipment) are easier to *decompose* in a consistent way than less well defined objects (e.g. operations).







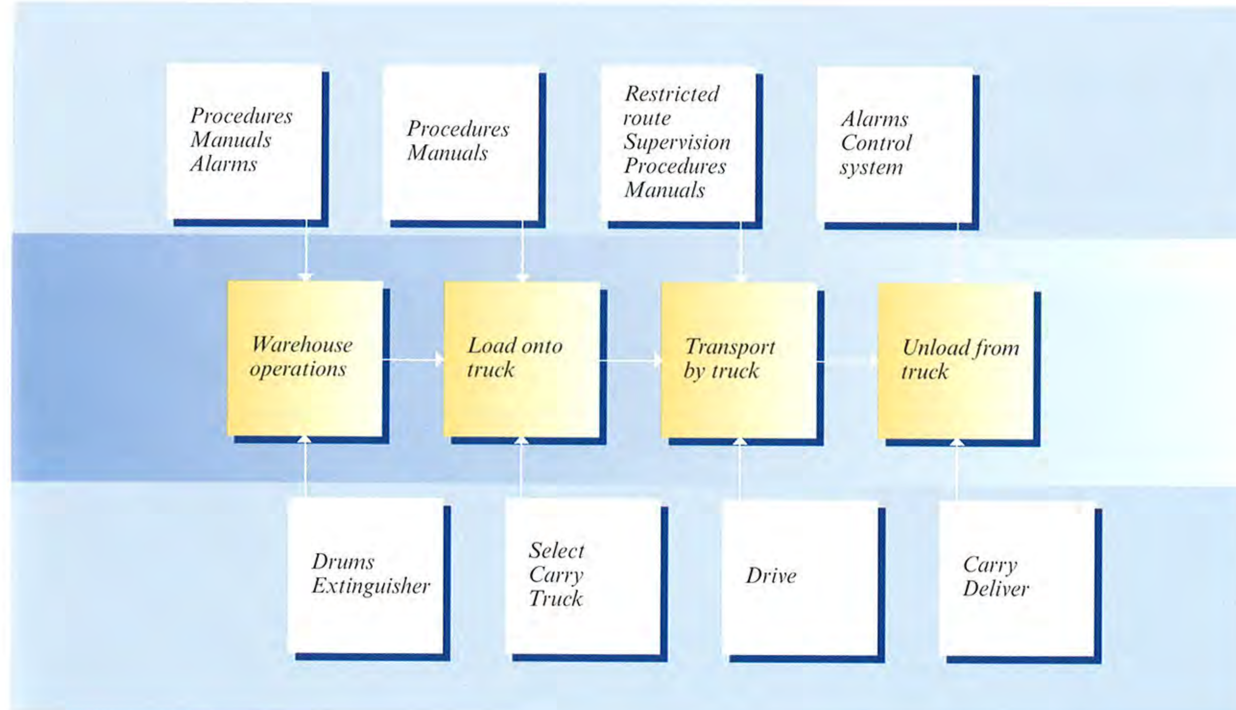



*Figure 2. Functional description: Provide chemical XYZ.*

Producing the model top-down to the required level of detail worked as intended. If the *hazard analysis* is performed in a top-down fashion there is a tendency to throw up the same problem several times in different places. Performing the hazard analysis bottom-up allowed a more rational treatment of duplicate hazards than when it is performed top-down and it is clearly the preferable procedure.

The development of *incident scenarios* provided a good understanding of the sequence of events that contribute to the development of an incident course. This also provided a solid basis for identifying human tasks and management functions associated with the hazards.

The method developed for the *analysis of human and managerial factors* proved to be helpful and more practical than, for example the commonly used method MORT, in the analysis of managerial factors. The main benefit is that the link between process/hardware problems and the managerial/operational tasks can easily be determined.

The principles of a hierarchical functional description and preliminary screening of hazards proved to be cost-effective when large plants are studied. The development of incident scenarios and identification and integration of human- and management-related tasks seems to be a useful approach for incorporating these factors into safety studies. The approach will be further developed in a ongoing project concerning the planning of emergency training scenarios, as it is recognized that the safety and emergency problems of major complex systems do not belong exclusively to either technical or human factors, but managerial elements do also have a large impact on the safety and emergency operations.

*Publication in 1994: 101*

BIRGITTE RASMUSSEN

# Dense Gas Data

The analysis of accidental releases of pressure-liquefied gases is an important issue in risk assessment. During such releases so-called 'dense' or 'heavy' gas clouds are formed, even if the gas as such is lighter than air. The reason for this has to do with the need to store the gas under pressure as a liquid. During the release violent boiling/flashing takes place atomising the liquid into gas and tiny airborne aerosols, most of which evaporate while still in the air. The heat of vaporisation is supplied by air mixed into the cloud, resulting in an extremely cold gas/air mixture. Temperatures as low as -80°C have been observed in clouds containing 10% ammonia. Due mainly to the cooling of the air component, the density of the cloud becomes much higher than that of the ambient air, causing the cloud to sink to the ground and spread as a shallow 'blanket'. Evidently this is an unwanted behaviour, because most human activity is concentrated at the surface level.

The dispersion of dense gas has been a research topic at Risø for a number of years. At present two ongoing EC-sponsored projects, FLADIS and REDIPHEM, involve dense gases.

FLADIS is a large project under the EC research programmes STEP and ENVIRONMENT in which groups from most EU member states, plus Sweden and Finland, participate. The project consists of a number of experimental as well as theoretical investigations focusing on thermodynamical effects and on the transition to neutral dispersion. Risø's contributions to FLADIS are to perform large scale field experiments with ammonia clouds and develop a dispersion model based on shallow layer theory. In 1994 the last (of three) experimental campaigns were completed and data have been distributed.

REDIPHEM is an ENVIRONMENT project performed by Risø and TNO aiming at collection, analysis and dissemination of results obtained in EC research programmes on dense gas releases. In 1994 a prototype database was made containing dense gas data from wind tunnel and field experiments. Institutions in Europe and in the United States have contributed to the data base, which will be made available at the end of the project (in 1995). The data base contains available information on the experimental setup, sensor characteristics, data processing and other information needed to understand the experiments and to avoid misinterpretations of the results. At present the data base contains on the order of 20,000 time series.

Clouds in the sky show a great variety of complex shapes, a direct result of the atmospheric turbulence. In fact nature never produces the same cloud shape twice. Still, we can all recognise a cloud when we see one, even if we have actually never seen one exactly like it before. So clouds are complex, not totally random, and do possess reproducible features, which can be studied by means of statistical methods. In a dense gas cloud vertical movements are constrained by gravity squeezing the cloud against the ground and making it more two dimensional than ordinary clouds. Gravity also makes dense gas clouds slide down slopes in the terrain, in a more-or-less predictable way. A second effect of the density stratification is the damping of the turbulence inside and above the cloud, making the cloud tend to set up its own turbulence independent of the state of the atmosphere. These features should, to some extent, reduce randomness in the dispersion of dense gas clouds. An example taken from data obtained during the FLADIS field campaign in August 1994 is given in figure 1. The figure shows cross-plume concentration profiles obtained with a lidar (laser back scattering) device, which has a high spatial resolution. The randomness of individual profiles is very obvious. On the figure is also shown a plot of the distance-neighbour function derived from the data. The distance-neighbour function is essentially the distribution of cross-plume distances between pairs of ammonia molecules in the cloud, and it can be used to deduce geometric characteristics such as the average cloud width. In contrast with the instantaneous concentration profiles, the experimental distance-neighbour function has a high degree of reproducibility, and it turns out to be very nearly exponential.

There is a great need for reasonably accurate predictions of the behaviour of dense gas clouds formed during accidental releases. Such predictions are, however, not easily made, since turbulence, which is a tremendously rich phenomenon, is involved. Most models produce a definite output from a given set of release conditions, whereas experiments show a large degree of variability. At best such model results should represent reasonably well what could happen, but at present more knowledge is required concerning the variability of experimental results. As the example given above indicates it is also important to extract the right parameters for comparison. By collecting as many experimental results as possible in a joint data base the intention is to shed more light on these issues, and improve methods for testing models, a subject that will be highlighted in the new EU research programme on industrial safety.

*Publication in 1994: 85*

Søren Ott

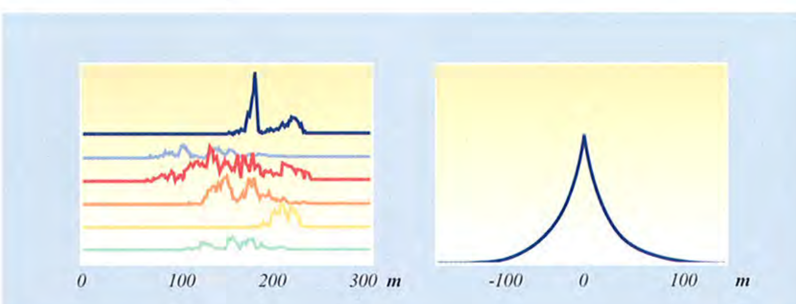



*Figure 1. Left: Instantaneous cross-plume concentration profiles of ammonia cloud. Right: The experimental distance-neighbour function derived from the same data sheet.*

*A vertical release of pressurised ammonia. Due to thermodynamical effects the cloud sinks to the ground.*

# Information Systems for Operation and Maintenance of Process Plants

The development and design of information systems to operators and maintenance planners of complex plants are the subjects of an ongoing project with the OECD Halden Reactor Project in Norway and a part of the Nordic Nuclear Safety Programme. The research involves the human factor area with tests of the interaction between operators and the information systems supporting the operator in the diagnosis task in the event of an abnormal situation. The support systems are tested in a full-scale simulator of a Finnish nuclear power plant using the Finnish operators as test persons. The tests give information on how to improve the information level given to the operators as well as how to avoid overburdening an operator with unnecessary information.

The main task of an operator is to supervise the operation and be prepared to act at once on alarms. In the design of new information systems it is important to include options that will prepare the operator for any contingency. One of the requirements on the displays developed within this project is to provide the operator with the ability to detect incipient failures, when possible, before the failures propagate and give rise to an alarm. Some incipient failures result from wear or other kind of degradation of the components, which might well have been indicated to the operator at an earlier state.

Another requirement on the display system is to present an overview to the operator about the functions, conditions and dynamics of the plant. An overview of the functions means that the operator can see where in the plant and in which components the changes of, e.g. temperatures and pressures take place. By the dynamics of the plant we mean that the changes in, e.g. temperature and pressure are displayed. By the condition we mean that the actual functions of the components are shown together with the functions they should have performed, if no wear nor other kind of degradation takes place in the components.

The display should also give the operators prompt information about a sudden failure and the consequence to the operating conditions caused by this failure. This means that the overview of the operating conditions must be easily understandable and display the key variables, so the operators are able to act immediately based on the screen information without the need for extra investigations for further information.

The display system must take care of both safety-related information and information necessary for operating the plant.

To gain an insight into the information related to safety, the following questions must be answered:

- What are the safety problems of the plant?
- Which situations must be avoided?
- How can these situations occur?
- How can these situations be observed?

On the question of observing degradation due to wear and incipient failures, it must be taken into account that one task for the control system is to compensate for minor deviations in the process, and therefore the control system will usually hide incipient failures.

For the task of supporting maintenance, it was mentioned earlier that the condition monitoring system was able to follow wear and degradation of components in order to be able to take them out of duty before they fail. The optimisation of maintenance is that preventive maintenance be engaged in just before the component fails. The history of the components in terms of their failure and maintenance reports gives the possibility of seeing whether or not maintenance is performed optimally and it also recommends what changes are necessary.

In 1994 an overview display which satisfies the above-mentioned requirements has been designed (Figure 2). The display consists of a mixture of a mimic diagram and curves, drawn as polygons, representing the key parameters of the plant. The display is developed and tested to a certain limit on the simulator.

The curves show the temperatures, pressures and flows of the primary, as well as the secondary and tertiary loops of the plant. The polygon will consist of horizontal and vertical lines. The positions of the connecting points of the curves are in a horizontal direction correlated to the mimic diagram and the position of the sensors in question. The positions of the points in the vertical direction are determined by the measured parameter values. The points are connected by straight lines. To avoid any possible confusion as to what are the measurements in the preheater and turbine systems, the preheater curve is drawn as a dotted line in the same colour as the curve through the turbine side. One polygon represents the steady-state condition, so it is possible to see deviations from the intended condition.



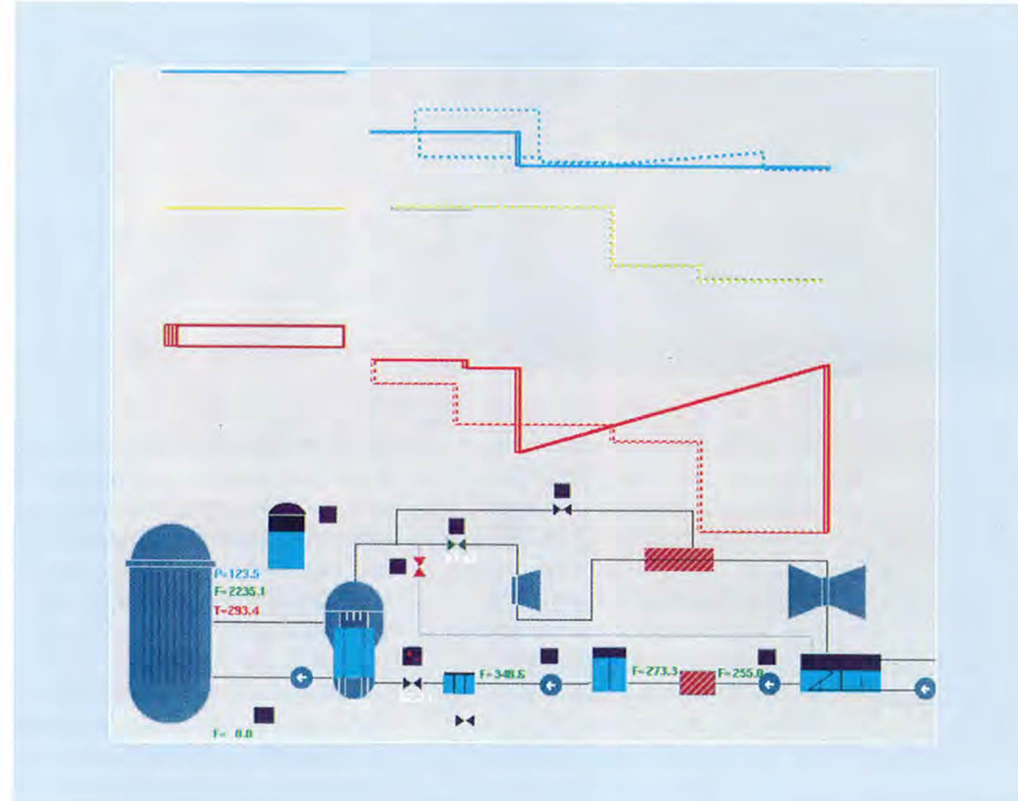


Figure 2.

The water levels of the pressurizers, steam generators, feedwater tanks and condensers are shown as levels in the mimic diagram. If the levels are increasing an up-arrow will be shown for the level in question, and vice versa, so that a decreasing level is shown with a down-arrow. Actions in the control system are shown in the same way as the levels. If the control system speeds up a pump an up-arrow will be shown in the control box of the pump, which is shown in the mimic diagram. Key values of the parameters will be shown as numbers too in the mimic diagram in the traditional way at the point where the values are measured. The display will also have some boxes where the more detailed information of the systems or components can be selected with either a trackerball or the keyboard.

Information about components comprises the condition of the component, where the deviation from anticipated operating characteristics can be observed and the results from statistical treatment of the component historical data. The historical data gives sufficient information to assess unavailability, failure rate, failure types, early failure after repair, relation between preventive and corrective maintenance and also if maintenance is performed at appropiate intervals. Figure 1 shows a time series of repairs on one component, where the repairs are classified either as preventive or corrective maintenance. From this simple line it is possible to look for early failures after repair, indicating bad repair work or bad spare parts. It can also be extracted if the relationships between corrective and preventive repairs is resonable. This type of graphic illustations will be further developed during the project.

The aim of these project is to develope and contribute with new viewpoints and methods to improve operators and maintenance planners daily work and give them an improved understanding of plant behaviour, wear and degradation. Important parts of the work is the developement of mathematical and statistical methods to elicit maintenance performance, investigation in plant design and function to be able to elicit the operational problems but also to develop information systems, mainly in the form of computer display systems, which can give the right information at the right time to the right persons.

*Publications in 1994: 69, 78 and 87*

Jette Lundtang Paulsen

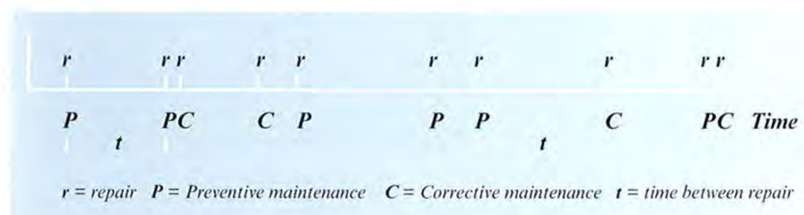



*Figure 1.*

## Cognitive Systems Group

# Multi-modal Technologies for Recording and Analysing Operator Behaviour

Modern complex work environments are remarkably vulnerable to the often harmful and sometimes disastrous effects on their safe and efficient operation created by so-called "human error". For instance, the principal causal factor behind 60 to 80% of all commercial aircraft and commercial shipping accidents is, as agreed by all standard sources many different observers agree, due to some form of human error. This percentage will be the same, it is generally assumed, in other complex work environments such as process control and operating rooms. It is therefore important to develop and apply techniques for identifying error-forming factors in specific work environments. To do so rigorously, however, requires tools and methods of observation and analysis which only recently have become feasible.

The Cognitive Systems Group has completed the development of the first version of a tool, MULTIMO, which supports a comprehensive synchronous logging and recording as well as a highly detailed analysis of the behaviour of operators. The target work environments to be studied using MULTIMO are process plants, aircraft cockpits, ship bridges, operating rooms or anaesthesia simulators - that is, complex technical domains where human performance and human-machine interaction are essential for safe and reliable operation. Thus, MULTIMO will enable human factors specialists

- to analyse and identify correlations among operators' behaviours and work environment characteristics – e.g., correlations between alarms, detection times and subjects' activation of controls – and
- to compare such correlations across different individuals, tasks, scenarios or training backgrounds as well as different types of control interfaces and task procedures.

While synchronous audio and visual recordings have been made for many years, it has only recently become feasible for human factors specialists to compare transcriptions of verbal output with synchronous video sequences and in fact, operate a video recorder via a PC. However, in order to assess operator behaviour in, say, a real aircraft or an aircraft simulator, it is often desirable to have a record of several of the behavioural *modalities* of the subjects. For instance, besides audio recording of verbal output, one may wish to have recordings of eye movements and fixations as well as of hand movements and body posture. Moreover, it is not enough that such logs and recordings be available separately; what is needed is a synchronous replay facility which can display any combination of logs and recordings and which will support "dynamic links" between items or scenes of different logs/recordings.





*When pilots' behaviour and performance are tested in flight simulators it is necessary to record synchronously eye movements, handmovements, communication and activation controls.*

Tracking the fast flow of information in these types of environments has been inherently time-consuming and error prone when using traditional observational research methods. This has put strong limitations on the number of cases analysed and/or the contextual deepness explored. It may take several hours just to analyse the visual attention allocation of a single operator during ten minutes of process control – and then his/her verbal communication and his/her activation of control devices have to be analysed in addition. Often the ratio of analysis time to observational session time ends up being 50 to 1 or even more, and for all practical research purposes this is unacceptable. The MULTIMO system will aid in bringing this ratio down.

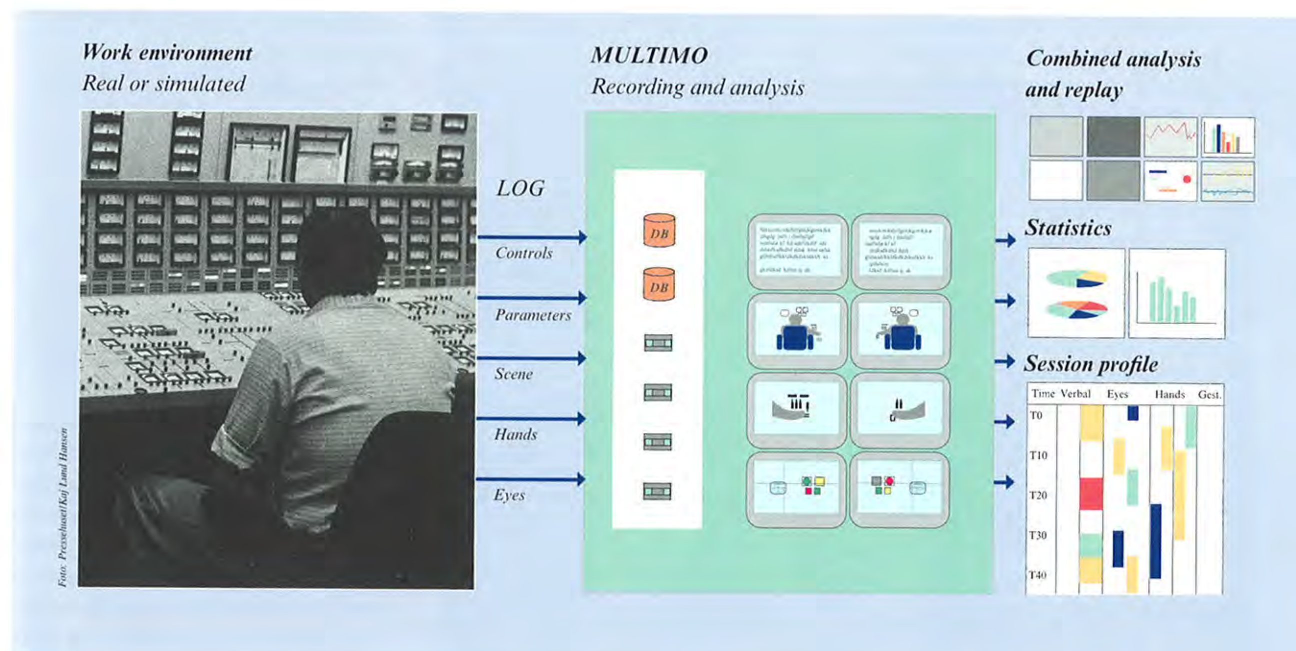
MULTIMO supports the research process at four stages: (1) recording and logging, (2) categorisation and scoring, (3) statistical analysis and (4) visualisation and reporting. The types of behaviours that typically will be recorded are eye movements, hand movements, separate views of the total work scene, stereo recordings of speech and signals of the work environment; and the activation of controls (when and where switches and dials are turned, their position) as well as selected work environment parameters (e.g. alarms and process state variables).

The immediate plans for exploiting the facilities of the MULTIMO system are to put it into use in several of the group's current projects. Thus, it will be used for (1) measuring the effect of training on flexible, touch screen control panels versus training on conventional knobs-and-dials panels, (2) evaluating operators' diagnostic strategies and other cognitive behaviours in a nuclear power plant simulator, and (3) analysing anaesthetists' response to alarms and different types of equipment in a comprehensive anaesthesia simulator.

The group has had a fruitful collaboration with the MMI Group at the OECD Halden NRP on the use of the MULTIMO technology. In order to insure an early exchange of experiences with the MMI Group, a protocol to the data log format of the simulator at HAMLAB has been included in the very first MULTIMO version.

Requirements on MULTIMO system have been identified by the group while technical specifications and the development of the system have been carried out with extensive assistance from Risø's Department of Electronics and Mechanics.

Henning Boje Andersen and John Paulin Hansen




*Analysing observations from work environments is very time consuming. The MULTIMO system facilitates the research process from recording to reporting.*

# IT and Training Aspects of Emergency Management

During 1994 Risø has participated in a European project, MEMbrain, inside the framework of EUREKA. MEMbrain is a modular system which copes with emergency management. In this project Risø is responsible for two modules: the communication module that must secure efficient and safe communication among the various parts of the emergency managing organisation, and the training module that may be used for training of the emergency managing organization as well as for testing the procedures used by this organization.

The work related to the communication module has resulted in a prototype of an e-mail system – the Message Management System, MMS – especially dedicated emergency management situations. This prototype which has been implemented in co-operation with a Danish software company, IFAD, has been installed at the end-users of the first MEMbrain application, the Nuclear Radiation Protection Agency, NRPA, in Norway. Further development of this system will take place in 1995.

The work related to the training module will be based on another European project inside the framework of Environment, the MUSTER project. Even though MUSTER is being developed as a generic training system it has been dedicated two applications (see below) for which prototypes have been developed and will be demonstrated in January and February 1995, respectively.

*The setup for tactical training at the Danish National Fire College.*

### *MUSTER*

MUSTER – Multi-User System for Training and Evaluation of environmental emergency Response – is a training system especially dedicated to improve the co-ordination of efforts of decision makers in emergency management. The project was initiated in 1993 and planned for two years; it includes nine participants from four different European countries, and it is partially funded by EC.

One way of carrying out co-operative training is through full-scale exercises, i.e. exercises in which all aspects of emergency response are carried out physically. Only the physical process of the emergency, the fire, the explosions, etc. is not present.

Full-scale exercises are the most realistic training setup in order to train all aspects of a co-ordinated emergency response. This is, however, typically an extremely expensive form of training, and even more, a form which is difficult to control in detail. Thus, it is often unfeasible to pause or revert and repeat in case the evolution does not follow the line planned in advance in order to convey the most efficient training in relation to the objectives of the training session.

In order to overcome the drawbacks of full-scale training, training systems like MUSTER are used. The state of the art is illustrated in the figure showing the setup for tactical training at the Danish National Fire College. Here a town model, scale 1:100, has been built up like a typical Danish town of medium size, and the training of decision makers takes place in this environment.

In fact, the MUSTER system is based on the same concepts. However, the aim of MUSTER is to build a computerised system that will overcome some of the problems related to the town model, e.g. to avoid the unrealistic overall view by the trainee of the complete environment, to give the trainee a better feeling of realism by letting him play against realistic simulations instead of the good (or bad) will of the training supervisor, and to support all phases of a training session. So, the support offered by MUSTER embraces the phases of planning, execution and evaluation. Similarly, the objectives of MUSTER are threefold:

- to support trainers or "drill supervisors" in the planning phase – by offering an authoring environment – in developing training scenarios based on specific training needs, the possible vulnerable objects, and the available resources, human as well as technical;
- to support the supervisor and his/her aides during the execution of a training scenario, by offering a simulation of the emergency environments giving the supervisor the best possible overview of the situation, the events automatically or manually carried into effect, and the actions of the trainees; furthermore, to support the presentation of the actual situation to the trainees in a plausible way as compared with the visual impression they would have in a real life situation;
- to support the supervisor in the debriefing or evaluation phase by allowing him/her to review and present in an easy way specific situations selected during the scenario execution.

Besides the ability to control the training scenario in great detail by using the training environments, the MUSTER system will moreover allow training of a selected part of the emergency managing units by letting the role of the remaining parts be taken by the supervisor or his/her aides. All communication with these units will be responded to by the supervisor in a way similar to the possible response from the missing unit; so the trainees will have no indications if they are co-operating with a real emergency managing unit or with someone playing that role.

The kernel of MUSTER comprises:

- a centralised data base;
- a handler taking care of the communication between various modules and the data base as well as of the timing of causal relations in the scenario;
- the scenario tree presenting to the supervisor the possible routes to follow in the interactive scenario execution;
- a GIS (Geographic Information System) system supporting the supervisor in the overall overview of the environment and the status of the situation;
- a logging system to be used partly for a post mortem analysis supporting the debriefing and analysis at the end of the scenario, and partly to support the possibility of going back a number of steps in the scenario to avoid a scenario evolution not in line with the objectives of the training.

Furthermore, in addition to the MUSTER kernel one may use external simulations that may be called and executed by the MUSTER system. Examples of such external simulation could be such things as forest fire, weather conditions, dispersion calculations or train control, dependent on the needs of the actual scenario.

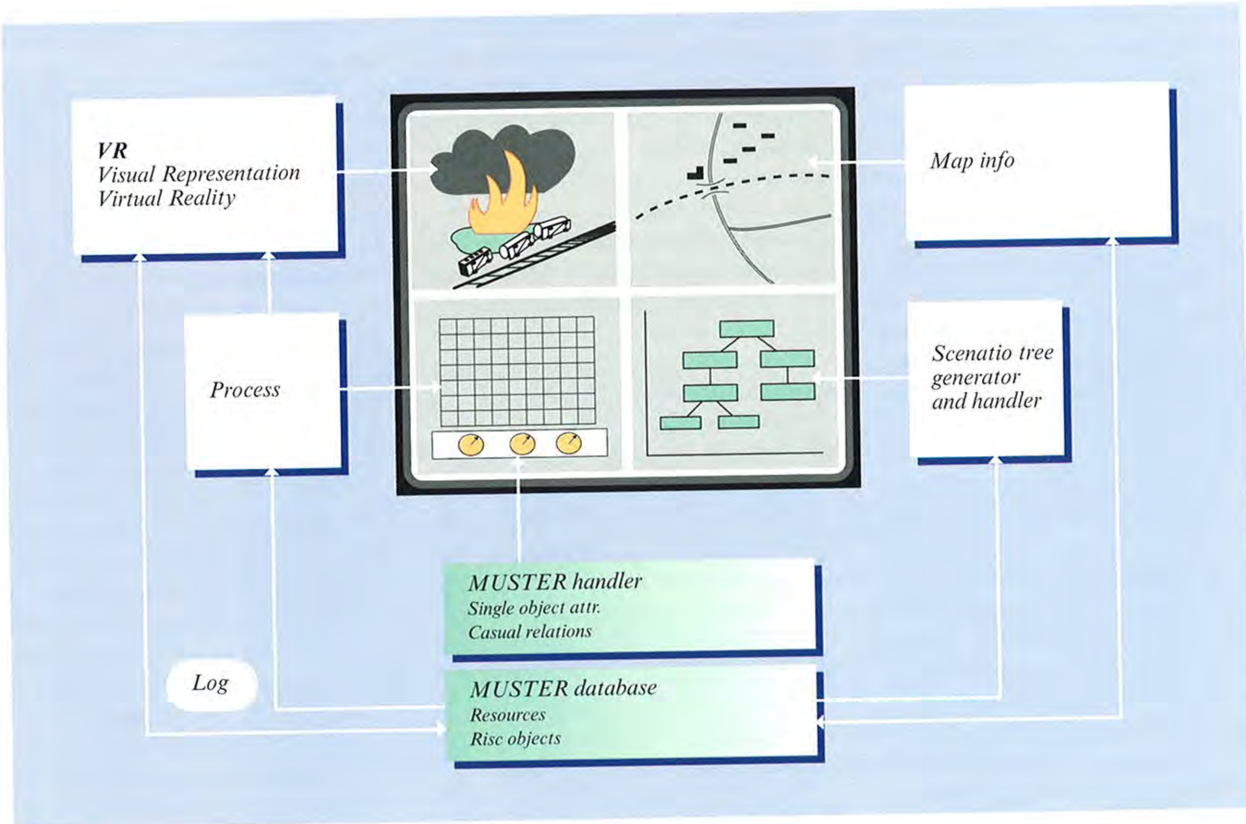
Based on the MUSTER kernel and the choice of external simulations, a large variety of scenarios may be fulfilled by the use of MUSTER. However, the first phase of demonstrations of MUSTER scenarios will be limited to two domains:

- one is the railway domain based on a fictive accident at the Danish railway comprising derailed tank wagons of which one is leaking toxic materials to be dispersed in the environments, and another one is jeopardised to explosion due to a nearby fire;
- the other is the port domain based on a real accident in 1986 in the port of Genoa comprising an explosion in an oil tanker with the implications of emptying the port area for other tankers jeopardised to the same destination.

The figure (overleaf) indicates the supervisor's desktop that will show at least four different views of the situation presented either on one screen as shown on the figure or on several screens.

The GIS system will present the overall view of the scenery, showing the environment, the scene of action including the threatened object and the resources available for the rescuing process. In case of fire the GIS system will show isocurves of temperatures to indicate the area in which rescuing people may or may not be able to act. Likewise, in case toxic materials are released, the GIS system will show isocurves of the concentration of the toxic cloud in order to indicate the risk of victims and consequently the order in which they should be res-

*MUSTER training supervisor desktop*




cued; and in addition the isocurves will show the need for protective equipment for the rescuing personnel. Furthermore, in relation to the window of visual presentation the GIS window will indicate the line of sight of the decision maker at the site with subsequent consequences for the information to be shown for the trainee.

The scenario tree will support the supervisor during the execution of the planned scenario from the point of view of reminding him/her of his/her own choices at a given time of the scenario as well as from the point of view of indicating reasonable choices of the trainees in specific critical situations. Furthermore, in time dependent critical situations the scenario tree may initialise the handler to take care of the timing in order to decide – based on programmed simulations and the action of the trainees – if, e.g., a given threatened object will explode.

The process window may show information from the data base, from one of the external simulations, or, e.g., it will allow input from the supervisor for the execution of a simulation.

The window for visual presentation may show to the supervisor the visual impression one may have from a given position at the site looking in a given direction; or the supervisor may choose to have this window as a slave of the window shown to the trainee. The latter may be controlled by the trainee himself by indicating his/her position and line of sight to the system. Whereas the visual presentation of MUSTER in the first demos will be based on still-pictures and possible brief video sequences, this presentation will be the object of improvement in the nearest future by implementing the use of virtual reality in order to improve the realism felt by the trainees in performing the situation assessment.

Although most computerised training systems today have a sequential succession of events regardless of the counter actions of the trainees, the most important result of MUSTER is the development of an interactive training system in which the trainees will see the influence of the scenario as a consequence of their actions; and thereby have the feeling of a more realistic and, hopefully, a more efficient training session.

As mentioned above, the first presentation of MUSTER will be related to two site- and national-dependent demonstrations inside the domains of railway and maritime port areas in Denmark and Italy, respectively.

*Publication in 1994: 57*

VERNER ANDERSEN



# COOPERATIVE ASPECTS OF COMPLEX MANUFACTURING TASKS

Computer technology has since its beginning proved a very forceful innovation, supporting manufacturing organizations in getting the work done more effectively and efficiently. Computer-Aided Design (CAD) tools support engineering designers in specifying products, and Computer-Aided Manufacturing (CAM) tools, for example, help process planners determine how to manufacture the components. Since 1984, researchers in the field of Computer-Supported Cooperative Work (CSCW) have been studying how to apply computer technology to support people in coordinating their work, i.e., determining who is doing what, when, how and why. The field study of a concurrent engineering project, reported here, is part of a research effort at Risø to formulate a theory for and prototypes illustrating how computer technology can support the coordination of work and how this particular technology relates to technologies supporting getting the work done. The core of Risø's work in CSCW is the theory of coordination mechanisms developed in the COMIC (Computer-Based Mechanisms of Interaction in Cooperative Work) project.

### *Concurrent Engineering*

Most of the empirical investigations within the field of CSCW focus on how a relatively small number of people coordinate monitoring and regulation tasks in time-critical settings. This field study served the purpose of refining the coordination mechanism theory and assessing the validity of it in a product development setting, involving a large number of people. Qualitative data on coordination in both the engineering design and software design domains in one particular manufacturing project were collected from interviews, observations and project documentations.

Concurrent engineering has proven a viable approach to enable manufacturing organizations meet the increasing market demands for flexibility and shorter lead-times. Organizing product development as concurrent engineering implies bringing information from all stages in the product life-cycle – development, production, use and destruction – up front to the development phase. As an example, information about the destruction of the product can affect the actual design decisions. Assume that component A is technically superior to B, but choosing A implies a potential environmental hazard. Then it can be a more economically as well as a more environmentally sound decision to choose component B if the company by law otherwise will be responsible for collecting all A-components from their customers. Choosing B can, however, lead to radical changes in the product design.

Bringing information about the constraints and possibilities for designing products imposed by production, use and destruction, implies that many people with different areas of competence will have to be involved in the development effort. Applying concurrent engineering, therefore, increases the complexity of coordinating the work.

*The new instrument for analytical testing of raw milk at Foss Electric.*

### *Coordinating Concurrent Engineering*

Foss Electric A/S (FE) in Hillerød was chosen as the field study site because the company is at an advanced stage in implementing a concurrent engineering mode of operation. The company manufactures equipment for measuring quality parameters of agricultural products such as dairy products, grain and meat. The highly complex instruments are primarily sold to laboratories, dairies and slaughterhouses. Projects at FE typically involve a number of participants each competent within a specialized area, such as: mechanical engineering, electronics, software engineering, optics, chemistry, draughting, process planning, production planning, marketing, quality assurance, quality control and assembly. The field study concentrated on the System 4000 (S4000) project. The objective of this project was to build a new instrument for analytical testing of raw milk. The instrument consists of approximately 8000 mechanical and electronic components, and approximately 200,000 lines of software code. The S4000 project was one of the largest development efforts FE have undertaken. It involved up to 50 people at a time for more than 2 years, and was therefore suitable for testing out the coordination mechanism hypothesis in a complex setting.

At Foss Electric, meetings are one of the primary means of coordinating the work. In their daily work, project participants engaged in an abundance of informal meetings, as well as in a number of regular planned meetings. In order to manage the complexity of a project such as S4000, where a multitude of highly specialized skills had to be applied, meetings are, however, not sufficient for documenting and coordinating the work. CAD models, forms, boards, classification schemes were applied. Some of these artifacts, such as the CAD models, contained information only on the properties of the instrument. Others helped the participants coordinate their work by stipulating who should do what. These coordination mechanisms consisted of a form or a classification structure and were filled in and used according to specified procedures and conventions.

### *The Augmented Bill of Materials*

The Augmented Bill of Materials (ABOM) is an example on how changing a form that contains only information about the instrument to a coordination mechanism can reduce the need for face-to-face coordination.

One of the planned meetings in the S4000 was held each week. It had the purpose of coordinating the production of components for the prototypes. These prototypes are made in order to optimize the fit between designs, process plans, and production plans. Engineering designers, draught-persons, process planners and production planners participated in this meeting. In order to document decisions on the type and number of components in each subassembly, a standard Bill of Materials (BOM) was used. At some point, the S4000 project team decided to augment the BOM with information on how to coordinate the distributed tasks. They also specified a procedure for when and how each of the participants should fill in the various fields in this new paper-based ABOM, and to whom they should send the form after having filled in the part for which they were responsible. This provided the possibility for coordinating and communicating the status of the tasks without having a weekly meeting. For example, instead of having to ask the production planner about the status of a particular component, the engineering designer could see the production planner's estimate of the delivery week on the ABOM form.

### *Coordination Mechanisms*

The ABOM system is only one of several coordination mechanisms identified and analysed in the field study. Other examples are: (1) the CEDAC board (Cause and Effect Diagram with the Addition of Cards) for integrating mechanical design and process planning; (2) the product classification schema supporting classification and retrieval of CAD models; (3) software platform artifacts supporting coordination work among software developers; and (4) the bug-report and software error list for coordinating distributed detection and correction of software errors. Paper-, board- and computer-based forms much like these are quite commonly used in manufacturing organisations. Hence, their identification and description is not the primary result of the study. The analyses of the use of these artifacts as means of reducing the complexity of coordinating distributed concurrent engineering tasks are the primary contribution.

In concurrent engineering projects, coordination and negotiation play a key role exactly because when designing products with specific attention given to later stages in the product life-cycle, a large number of participants must be assumed. Much of this coordination will take place in meetings. The use of computer technology can, however, reduce the complexity of this coordination work, making product development more efficient. Our research results have served as an important input to the effort of establishing a theoretical framework for computational coordination mechanisms. The coordination mechanism theory can help companies design mechanisms targeted at reducing the need for face-to-face coordination. We are currently engaged in a re-design of the bug-report together with software designers at Foss Electric, with the purpose of providing computer support for distributed software testing of the instruments.

This project has been a joint effort between Risø and Institute of Manufacturing Engineering, Technical University of Denmark. The research is closely related to, and partially funded by, Strand 3 in the ESPRIT BRA 6225 COMIC project, and the CODEM project sponsored by Fisker og Nielsens Fond, Ib Henriksens Fond, and the Danish Technical Research Council.

*Publications in 1994: 63, 64, 66, 67 and 119*

CARSTEN SØRENSEN AND PETER CARSTENSEN

***Augmented bill of materials: Experiment/functional model/prototype***

| | | | | |
|---|---|---|---|---|
| Instrument: | *Name* | Type ID: | *ID number* | Page of pages |
| Unit: | *Unit name* | Batch size | *Integer* | Date: |
| Designer: | *Name* | Draught person: | *Name* | |

| ***Categories*** | ***1. component*** | ***2. comp.*** | ***.19. comp.*** | ***Responsible*** |
|---|---|---|---|---|
| Component ID | *ID + version* | | | Draught person |
| Description | *Text* | | | Draught person |
| Model name | *Model database ID* | | | Draught person |
| # Pr. instrument | *Integer* | | | Draught person |
| Model shop | *Check* | | | Draught person |
| Subcontractor | *Check* | | | Production planner |
| Production | *Check* | | | Process planner |
| Surface processing | *Check* | | | Project purchaser |
| New input materials | *Check* | | | Draught person |
| Machine ID | *ID number* | | | Foreman |
| CAM program | *Type of CAM prog.* | | | Foreman |
| Measure program | *Check* | | | Process planner |
| Foreman | *Initials of foreman* | | | Foreman |
| Delivery week | *Week number* | | | Production planner |
| Alt. delivery week | *Week number* | | | Production planner |
| Production time | *Estimated time* | | | Production planner |

Controlled by process planner: *Signature*

*The augmented bill of materials (ABOM). Each ABOM form holds information of up to 19 components for the same unit in the same instrument. All italics are our additions. The original is inverted, i.e., the rows in the figure are columns in the original ABOM. The original has 19 rows, corresponding to 19 different components. These are illustrated in three columns. This inversion is made in order to depict the whole ABOM and not only part of it.*

# Coordinating Distributed Activities in Producing Technical Documentation

### *The project*

The purpose of the Ph.D.-project: "Computer support for distributed cooperative manipulation of mechanisms of interaction" is to identify and analyse mechanisms of interaction that occur in large-scale cooperative work organizations and to examine system requirements in relation to a distributed cooperative maintenance of the identified mechanisms. Empirical data for the project were compiled during a three-month field study of tasks involved in the planning and production of extensive multilingual technical documentation at Grundfos International, Bjerringbro, Denmark. As part of the field study a work analysis report was prepared for the company. The main purpose of the field study was to form an empirical basis for an analysis of the theoretical and methodological assumptions that are applied in studying cooperative work, cooperative work arrangements, the coordination of cooperative work and in studying the mechanisms of interaction facilitating the coordination of the distributed cooperative activities.

### *The idea*

One of the challenges large-scale advanced manufacturing companies face today is to integrate different manufacturing functions as, for example, engineering design, product management, production processes, purchasing, sales, administration, marketing and technical documentation, and to support this integration by means of computers to meet the new challenges in an ever changing, dynamic and increasingly competitive market. These take the form of, for example, increased environmental demands, customization of products and reduction in product development time. The distributed and dynamic character of such large-scale cooperative work settings, where many or an indefinite number of persons may participate, the work needed to coordinate tasks becomes extremely demanding and complex. To reduce the complexity of the coordination activities people will apply various forms of mechanisms of interaction. To support coordination of cooperative work by computers, these mechanisms of interaction will have to be implemented in the systems. In designing such computational mechanisms the analysis and the conceptualization of the requirements will have to rely on a careful examination of the concept of mechanism of interaction in real-life settings.

### *The field study*

In the field study, the concept of mechanism of interaction has been used in a systematic way as an experimental means for conceptualizing and modelling findings in order to put the construct to test. A mechanism of interaction can be defined as a:

> *device for reducing the complexity of articulating distributed activities of large cooperative ensembles by stipulating and mediating the articulation of the distributed activities.*

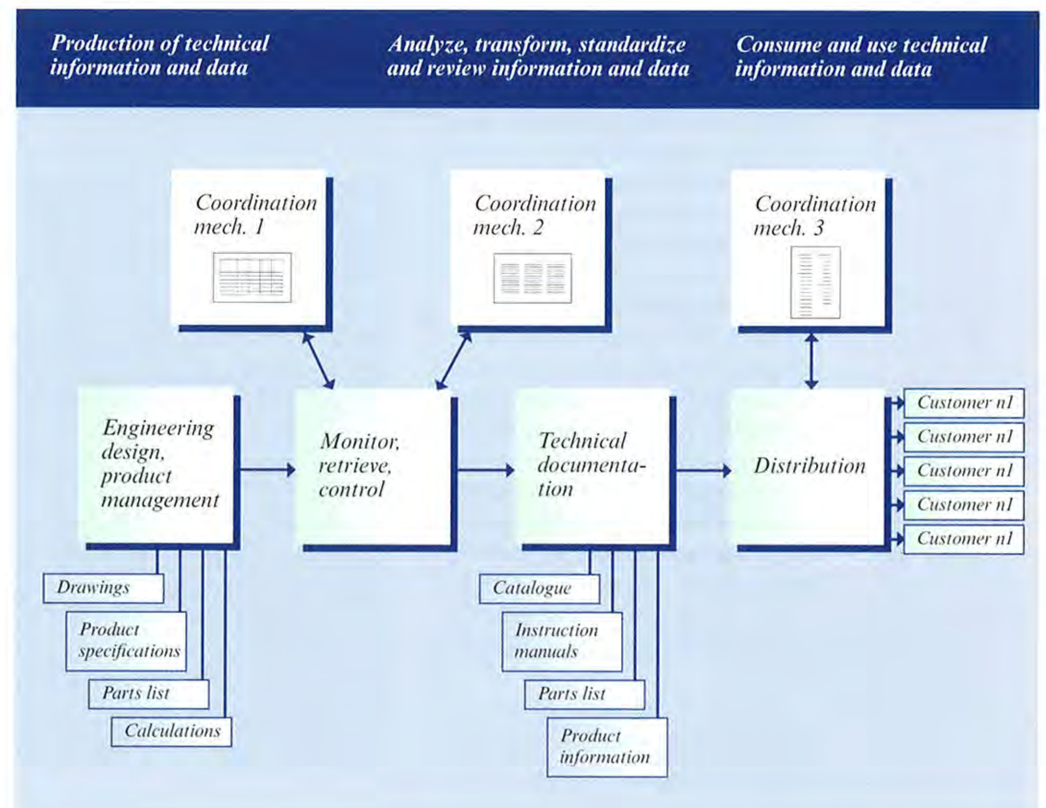
The concept of mechanism of interaction has been put to test by being used as a framework for analysing the use of symbolic artifacts in coordinating distributed activities in the production of technical documentation related to new product development at Grundfos International A/S, Denmark.
Grundfos produces pumps mainly for pure water pumping. In its field it is one of the three leading companies in the world. It has around 8500 employees in more than 30 countries. The main organizational units involved in the production of technical documentation are the engineering design departments, the product management department and the technical documentation department (see figure). The production of technical documentation in a large-scale manufacturing company is a highly complex activity. It involves a large number of people, who are scattered, not only around one factory site, but world-wide. Moreover these people are mutually interdependent in their work and they carry with them a whole range of different perspectives, objectives and competencies into the work process. The complexity is constituted by:

- Many mutual interdependent actors
- Different areas of competence.
- Many product variants – approximately 25,000.
- Many information objects – approximately 50,000.
- Product complexity and the heterogeneity of customer groups.
- Dynamism, e.g., increased customisation of products, very frequent products construction and design.
- Geographically distributed actors.

The sheer complexity and dynamic nature of the production of technical documentation set up a need for constant and sophisticated coordination work. That is, for constant communication between members of the cooperative arrangement (who are geographically dispersed sometimes on an international scale), for role, task and responsibility allocation, for the integration of the various tasks and, not least, for ensuring that task completion is timely, visible, and understandable for each of the members. Without this kind of work, the product analysis, transformation of data and product-reviewing functions could not be carried out successfully and efficiently. Managing the complexity of the coordination activities could not be achieved without coherent procedures, protocols, and, moreover, these are procedures and protocols to which each and every actor of the various cooperative work arrangements is committed. The procedures and protocols are facilitated by a series of mechanisms of interaction reducing the complexity of the coordinating activities required during the process of generating the product documentation for the customer. Three such mechanisms of interaction (see figure) are: the construction note (coordination mech. 1) related to the analysis, transformation and retrieval of technical information and data, the product key classification scheme (coordination mech. 2) related to the reuse of drawings and transforming and standardising technical information and data and the distribution list (coordination mech. 3) used in coordinating the distribution of the documentation.

To exemplify the concept of mechanisms of interaction applied in the analysis the construction note mechanism (coordination mech. 1) will be briefly discussed here. The construction note is a mechanism used within the company to handle and distribute semi-structured messages and notes regarding product changes and to handle and distribute proposals for product changes. It deals with problems regarding the coordination of propagation of changes and delegation of roles, tasks, activities, responsibilities, etc., regarding the changes. The overall function is to manage the propagation changes, i.e., to classify, control, monitor, coordinate, make publicly perceptible, make people aware of and negotiate the changes to products, parts, information objects, conceptual structures, etc. Furthermore it facilitates the allocating of people that are to carry out the needed tasks and sequences of action on the basis of the changes in question or to assign people the further responsibility to allocate resources for and mesh, monitor, coordinate, etc., change-related tasks. The mechanism stipulates the coordination of the distributed activities by providing a standard protocol that prescribes the appliance of specific rules and procedures in use.

The analysis of the three coordination mechanisms supports the view that people in order to reduce complexity in coordinating distributed activities do apply certain types of mechanisms of interaction




*A simplified model of the production of technical documentation and the identified mechanisms of interaction.*

that stipulates and mediates the co-ordination activities, by providing:

- A standard protocol which prescribes the appliance of specific rules and procedures in use and a conceptual structure for categorising and classifying symbolic representations of product parts (the construction note),
- a structure for the design of documentation that makes it possible, in a distributive manner, to navigate in and browse this documentation and a protocol for the unique naming of products and product variants (the product key classification scheme),
- standardised criteria, procedures and rules for what type of documentation to receive when and why (the distribution list).

In putting the concept mechanisms of interaction to test as a framework for the empirical analysis it has been proved that it is operational, it has contributed in conceptualising the requirements of computational mechanisms of interaction and it is useful for the requirements analysis needed in designing computational mechanisms of interaction. As part of the field study the company was provided a work analysis report containing suggestions for change in work procedures and introduction of new IT tools for obtaining a better integration of the technical documentation service with the company's design and development activities.

*Publications in 1994: 58, 59, 60 and 61*

Hans H. K. Andersen



# Design Explorer:

## Supporting Knowledge Exploration During the Design and Development Process

Modern design practice has evolved in response to changing economic, technical, and environmental conditions. Traditionally in an era of slower technology development, limited competition, and geographically bound production and distribution, changes from one product 'model' or system 'version' to the next were often moderate, and health or environmental risks associated with the use, production and disposal of a product could be empirically identified by trial-and-error. Engineering, marketing and distribution, manufacturing, usage, maintenance and repair, recycling and disposal could be considered more or less in isolation; knowledge about these aspects of the product had ample time to migrate among design team members.

This is changing dramatically. It is widely considered that today's mature markets, world-wide competition, and fast technological development require companies to adopt design and development strategies in which the engineering, market, distribution, manufacture, use, maintenance, repair, disposal and recycling of a product cannot be considered in separate, sequential phases, but must be considered together in an integrated design and development process. For example, a goal of many companies is to produce a very large volume of new and substantially different products or systems that meet changing environmental and health and safety regulations. This goal must often be achieved with limited resources. Thus, the exploration and integration of new technological advances in diverse fields such as software engineering, electrical engineering, telecommunications, materials, human-system interaction and end-user applications are increasingly required.

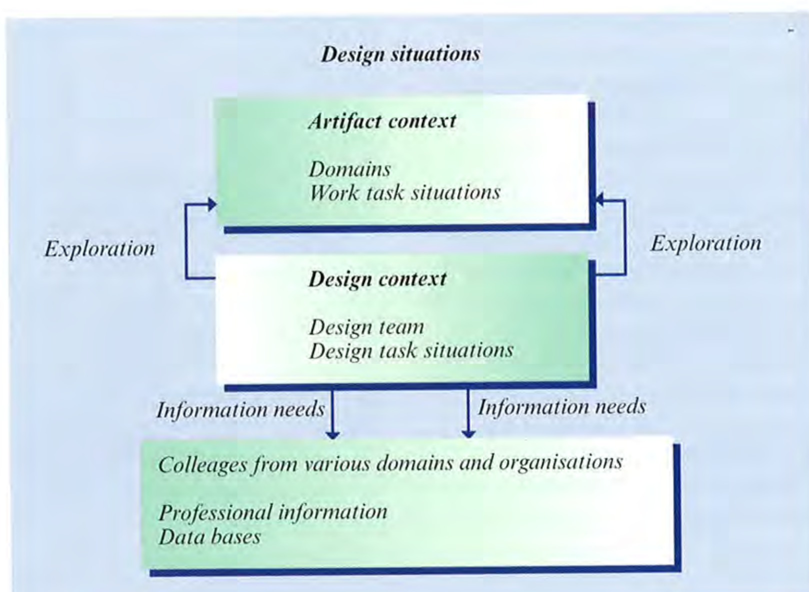



*Figure 1.*

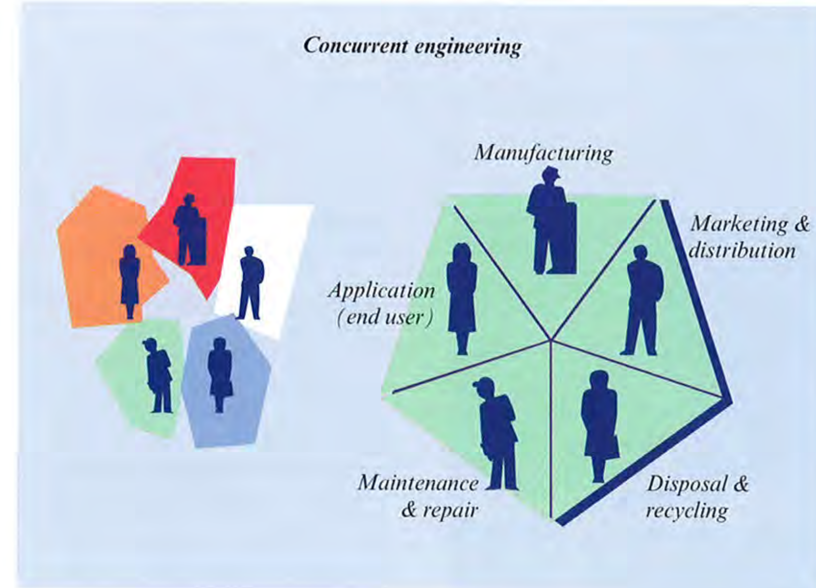




No individual design team member can acquire the current and expanding knowledge from such a wide variety of domains and information sources. Thus, the exploration of knowledge from different domains and contexts requires communication, or interaction, among domain specialists not all of whom may be found within an individual organization, company, or country (see Figures 1 and 2). Tools and methods for exploring current and expanding knowledge from such a wide variety of professional domains and information sources are needed.

As a first step towards the development of tools and strategies to support knowledge exploration and integration during the design and development process, several field studies were conducted to develop models that characterize knowledge exploration and reflect actual design practice. These field studies resulted in a series of interrelated models that describe types of information needed to create products, and social roles and inter- and intragroup communication networks and their evolution during the design and development process. During 1994 testing of these models began by studying an ongoing design project in northern Europe. The goal of this project was to create a new sensor to be used for environmental purposes. The design team included 27 participants with expertise in mechanical engineering, chemical engineering, material science, electrical engineering, software engineering, production, environmental engineering and applications, and marketing. Semi-structured interviews with participants were conducted during which participants discussed their work tasks, the information and communication strategies used during design tasks, and contextual factors that may have an impact on information and communication in design. The outcomes of this research included:

*Figure 2.*




- identification of the organizational, task, disciplinary, personal, and multiple boundary spanning roles and strategies that support knowledge exploration by providing access to information as well as filtering and translating information,
- a proposed conceptual representation of the design context, and
- hypotheses about possible ways to create improved design support systems (information, communication and documentation systems).

These results were reported at international conferences, workshops, and invited talks in Denmark, Russia, USA and the UK.

Future work includes the analysis of information needs and information-seeking behavior including the actual use and value of existing formal and informal information sources during the changing tasks of individual design team members, requirements for the development of improved information support systems, and the development and evaluation of prototype information support systems.

This research has been supported in part by the United States National Science Foundation International Programs under Grant No. INT-9301720 and by the North Atlantic Treaty Organization under a Grant awarded in 1993. The work will be continuing under a grant awarded by the Danish Research Council for the Humanities and in collaboration with Danfoss A/S.

*Publications in 1994: 88, 89, 90, 102, 111, 112, 113 and 114*

Diane H. Sonnenwald and Annelise Mark Pejtersen

# Conferences

***National Action to Mitigate Global Climate Change***

*International Conference Copenhagen, 7-9 June 1994*

Over 170 participants from 60 countries met for three days in Copenhagen in June to discuss how the aims of the Climate Convention could be translated into practical action. The Conference was organised by the UNEP Centre, with financial support from Danida, the Global Environment Facility (GEF), UNEP and Risø.

The main objective of the conference was to identify common approaches to national mitigation analysis. This should help countries in meeting their commitments under the Framework Convention on Climate Change (FCCC), and in setting priorities for national actions.

The discussion was focused around the following six subsections:

- Global Climate Change: Science, Economics and Policy
- Strategies to Mitigate Global Climate Change: Technology and National Policy Options
- Framework for Mitigation and Cost Assessment
- National Emission Abatement Cost Assessment
- National Mitigation Action: Further Analytical and Policy issues
- Summaries and Future Directions

The international organisations GEF, UNEP and the Climate Convention Secretariatet welcomed the conference as a very important contribution to the development of a common understanding of key issues in national strategy development such as methodologies for cost assessment, common assumptions and potential mitigation options.

National climate change mitigation actions will involve collaboration between developing countries and industrialised countries. Emission reductions as well as costs must therefore as far as possible be measured with a common standard against which to both assess necessary financial support and subsequent verification. This process clearly involves a number of politically and economically sensitive areas. For example, the reduction of GHG emissions is often intimately connected to essential economic activities in the countries concerned. Coal production in Zimbabwe, and the low energy prices common in oil-producing countries like Venezuela are two examples which were discussed at the conference. The crucial question again is how local social and development priorities can be reconciled with GHG reductions.

In spite of these politically controversial issues, the conference participants did arrive at a broad agreement on the needs and advantages of a coordinated effort to achieve the goals of the FCCC.

There was general agreement among the participants that the methodology must take account of the potential and limitations of each country, while living up to the convention's requirement for transparency and comparability. The UNEP GHG Abatement Costing Project, along with similar efforts in which practical country studies go hand in hand with methodological development, was given broad support. In general, participants recommended that the methods should be extended to cover more sectors and gases, to take into account regional cooperation and to include macroeconomic effects.

The conference itself may be seen as an important component of the FCCC process, with its high-level, and tightly packed formal programme of presentations together with intense informal discussion and exchange of ideas among researchers, national policy makers and representatives of the international organisations. The success of the conference in this regard was amply confirmed by the participants.

The Conference Proceedings will be published early in 1995.

# Publications

## Energy

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# Staff

December 1994

*Hans Larsen, M.Sc. (Elec. Eng.), Ph.D.* The Technical University of Denmark 1972. From 1973 to 1976 at Dragon project at AEE Winfrith, U.K. Risø from 1976. Energy Technology Department 1976-80, working with systems reliability. Head of Energy Systems Group 1980-84. Head of Systems Analysis Department from 1985. Member of the Danish Academy of Technical Sciences 1993.

## Cognitive Systems Group

*Leif Løvborg, M.Sc. (Elec.Eng.)* Risø from 1962. Radioisotope techniques (1962-66), nuclear geophysics and mineral exploration (1967-86). Group Leader (Electronics Dept.) 1965-86. Human factors research from 1986. Acting head of Cognitive Systems Group 1990-92. Head of Cognitive Systems Group since April, 1992. Main research activity: Experimental investigation of human cognitive behaviour in simulated "microworlds".

*Hans Henrik Krogh Andersen, M.Sc. (Psychol.).* Major subject:Cooperative management of classification schemes in electronic publishing, cooperative work, work analysis. Ph.D. student at Risø from February 1992. Subject: Computer-supported distributed cooperative manipulation of social mechanisms of interaction.

*Henning Boje Andersen, M.A. (Philos.)* Copenhagen University and Oxford University (logic, philosophy of language) 1976-79. Medical Faculty, Copenhagen University and Roskilde University (philosophy of science) 1980-83. Risø from 1984, Cognitive Systems Group from February 1990. Main activities: Human-computer interaction, systems support of emergency management and multi-user training, evaluation of training transfer.

*Verner Andersen, M.Sc. (Elec.Eng.),* Senior Scientist, Ph.D. Risø from 1966. Nuclear physics (1966-76), plasma physics (1976-86). Leader of programme on plasma-physics technology 1983-86. Information technology from 1986. Cognitive Systems Group from February 1990. Manager of CEC Environment project "Multi-User System for Training and Evaluating Environmental Emergency Response" (MUSTER). Responsible for Risø's part of the EUREKA Action EU 94 "Decision-Support Integration-Platform for Major Emergency Management" (MEMbrain). Main activity: Project management, systems development.

*Peter H. Carstensen, M.Sc. (Com. Sc.).* Dansk Datamatik Center 1984-1988, Labour Unions' Centre for Informatics 1989-1991. Cognitive Systems Group from February 1992. Main activities: Human-computer interaction, Computer Supported Cooperative Work, methodologies for analysis of work in complex settings, system development methodologies.

*John Paulin Hansen, Ph.D. (Psychol.).* Major subject: Simulation, visual perception, recording of eye movements, evaluation of interfaces, cognitive modelling. Risø from 1988, Cognitive Systems Group from February 1990.

*Betty Hewitt, M.Sc. (Comp. Sci.),* Queen Mary and Westfield College, University of London, England. Communications Industry 1985-1988, Researcher in the field of CSCW (Computer Supported Cooperative work), Queen Mary and Westfield College, and the University of Surrey, Guildford, England 1989-1993. From May 1993 until 31 July 1994, Post doc in Cognitive Systems Group. Main activities: theory, development and prototyping of computer support for mechanisms of interaction within the advanced manufacturing industry.

*Kenji Itoh, B.S. (Indust. Eng. and Management), Ph.D.* Systems Engineer, Hitachi Ltd., Ibaraki, Japan (1979-83). Assistant Professor (1983-91) and Associate Professor (1991-) in Industrial Engineering and Management, Faculty of Engineering, Tokyo Institute of Technology, Japan. Guest researcher at Risø 1 March - 27 December 1994 through a grant awarded by the Japanese Government. Main activities: Information displays, artificial intelligence approaches to production control, models of human operator performance.

*Ann Britt Miberg is M.A. in psychology* from the University of Copenhagen (1992). Ph.D. student at Risø (1993). Primary interest lies in the area of decision making, training and human-computer interaction. Works currently on a Ph.D.-project on training of decision making in simulated environments.

*Finn R. Nielsen, M.Sc. (Appl. Math. & Phys.).* Technical College of Copenhagen 1968-74. Risø from 1974. Computer programming for models and graphical interfaces within man-machine studies and operator support facilities, simulation of power plants for diagnosis and control (1974-1989). Cognitive Systems Group from February 1990. Main activities: Cognitive simulation, implementation of design concepts.

*Annelise Mark Pejtersen, M.A. (Sci. of Lit.),* Senior Scientist. University of Copenhagen 1971-73, Associate Professor at the Royal School of Librarianship 1971-82, Acting Professor 1983-85. Visiting Senior Research Scientist at Georgia Institute of Technology 1982-83. Risø from 1986. On leave as manager of the Labour Unions' Centre for Informatics 1989-90. Cognitive Systems Group from February 1990. Main activities: Project management, user modelling, ecological design concepts, multimedia interfaces, taxonomy of work domains.

*Kjeld Schmidt, M.Sc. (Sociol.),* Senior Scientist. Roskilde University 1972-85, Dansk Datamatik Center 1985-88, Labour Unions' Centre for Informatics 1989-90. Cognitive Systems Group from March 1990. Main activities: Theory and methodology for analysis of cooperative work in complex settings, Computer-Supported Cooperative Work, taxonomy of work domains.

*Diane H. Sonnenwald, M.Sc. (Com. Sc.), Ph.D.* School of Communication, Information and Library Studies, Rutgers, the State University of New Jersey. Bell Labs 1980-1985, Bell Communications Research 1985-1993. U.S.A. National Science Foundation International Postdoctoral Fellow 1993, Risø from 1993, NATO Post doc. Fellow, 1994. Main Activities: The exploration and integration of knowledge from different domains during the design process.

*Carsten Sørensen, M.Sc. (Com. Sc. with Math.) Ph.D.* Department of Mathematics and Computer Science, Aalborg University 1989-1992. Cognitive Systems Group from September 1992. Main activities: Computer Supported Cooperative Work, computer support of integration of design and process-planning in manufacturing (Design for Manufacturability).

*Steen Weber, M.Sc. (Elec.Eng.), Ph.D.* Risø from 1972. Computer codes for nuclear fuel management (1974-75). Risk Analysis Group (Dept. of Energy Technology) 1975-84, Acting Group Leader 1982-83. Leader of project on knowledge-based system for control of heat distribution (1988-89). Cognitive Systems Group from February 1990. Main activity: Advanced interfaces and databases for information retrieval systems. Project leader KAVAS-2 1992-.

## Energy Systems Group

*Niels Juhl Thomsen, M.Econ.* Danish Ministry of Education 1978-79, Danish Ministry of Housing and Building 1979-81, Danish Ministry of Energy 1981-89. Joined Risø as Head of Energy Systems Group in May 1989 until October 1994. Main activities: General energy planning and economics of renewable energy.

*Peter Skjerk Christensen, M.Sc. (Elec.Eng.),* Senior Scientist. Risø from 1958. Nuclear research and education (1958-69), reactor engineering and thermohydraulics including simulation models (1969-76), Energy Systems Group from 1977. Stationed in Cape Verde Islands as energy advisor to the government (1991). Main activities: Energy systems modelling. Renewable energy technologies. Energy planning in Eastern Europe and CIS.

*Jørgen Fenhann, M.Sc. (Physics with mathematics and chemistry),* Senior Scientist. Niels Bohr Institute 1977. Risø from 1978. Main activities: Development of energy planning models, new and renewable energy technologies, calculation of emissions from energy systems, and energy-environmental planning for Eastern European and developing countries.

*Poul Erik Grohnheit, M.Econ.,* Senior Scientist. Danish Building Research Institute 1969-71, town planning consultant 1971-72 and 1979-80, economic planning and budgetting in local government 1973-79. Risø from 1980. Main activities: Energy system modelling, economics of electricity generating systems, and electricity markets.

*Lotte Schleisner Ibsen, M.Sc. (Mech.Eng.),* Senior Scientist. Risø from 1984 in Research Section of the Engineering Department working on aquifer thermal energy storage. Joined Energy Systems Group in 1989. Main activity: Assessment of energy technologies especially renewable energy and long-term energy technologies.

*Christina Ingerslev, M.Sc. (Technological and Socio-Economic Planning) Ph.D.* student at Risø from February 1993. Major subject: Possibilities for reducing the $CO_2$ emission from dairies and papermills. Subject: Strategies for reducing the $CO_2$ emission from the manufacturing industry.

*Henrik Klinge Jacobsen, M.Econ.* Alm. Brand 1989-1991. Greenland Home Rule 1992-1993. Risø from December 1993. Main activity: Macro-economic modelling.

*Niels A. Kilde, M.Sc. (Chem.Eng.),* Senior Scientist. The Danish Steelworks Ltd. 1962-81. Research and quality control (1962), planning and administration (1967), casting department manager (1972), development and energy manager (1977). Risø from 1981. Main activities: Energy use in industry and transport, Emission inventories.

*Helge V. Larsen, M.Sc. (Elec.Eng.), Ph.D.,* Senior Scientist. Technical University of Denmark 1974. Storno A/S from 1975. Risø from 1976. Department of Reactor Technology 1976-77. Energy Systems Group from 1977. Main activities: CHP production, modelling of energy systems, economic models for the oil and gas sector, development of planning models for wind energy.

*Henrik Jacob Meyer, M.Econ.* Rockwool Foundation Research Unit 1990-93. Technical University of Denmark 1993. Risø from December 1993. Main activities: Environmental economics, externalities in the production of energy, valuation of environmental benefits and damages, economic consequenses of greenhouse gas abatement.

*Poul Erik Morthorst, M.Econ.,* Senior Scientist. Economist specialized in energy planning and macro-economics. Risø from 1978. Head of Energy Systems Group 1985-89. Main activities: General energy planning and modelling with emphasis on electricity demand forecasting, economics of renewable energy technologies, especially wind turbines.

*Lars Henrik Nielsen, M.Sc. (Phys.,Math.),* Senior Scientist. Risø from 1981. Main activities: Probabilistic methods and model development, technical-economic modelling, energy system simulation and assessment of energy technologies, especially renewable energy.

*Peter Stephensen, M.Econ. Ph.D.* Student at Institute of Economics, University of Copenhagen 1989-91. Specialized in theoretical economics. Risø from 1991. Main activities: Environmental economics and macro-economic modelling.

*Lene Sorensen, M.Sc. (Eng.), Ph.D.* Started at Risø 1990 as Ph.D. student. Major subject: environmental planning and uncertainty. At International Institute for Applied Systems Analysis in 1991. Activity: evaluation of the RAINS model. Post doc from 1st April 1993 with the Energy Systems Group. Main activities: integrated energy/environmental models, evaluation of models, uncertainty in planning, methodologies for multi criteria assessments.

## Risk Analysis Group

*Kurt Erling Petersen, M.Sc., Ph.D.* Risø from 1977. Department of Energy Technology 1977-84. Risk Analysis Group from 1984. Head of Risk Analysis Group from 1990. Deputy head of Systems Analysis Department. Main activities: Risk and reliability analysis and treatment of reliability data.

*Palle Christensen, M.Sc. (Elec.Eng.),* Senior Scientist. Risø from 1962. Electronics Department 1962-86, work on nuclear instrumentation, research instrumentation and reliability projects. Department of Information Technology 1986-88, work on networking knowledge-based computing. Secretary of Risø's patent council 1973-88. Risk Analysis Group from 1988. Main activity: Risk and reliability analysis and development of computer codes for reliability and safety analysis.

*Atoosa Jalashgar, M.Sc. (Elec.Eng.)* from Institute of Electronic Systems, Aalborg University (1992). Ph.D. student at Risø and Technical University of Denmark from 1994. Activities: Failure analysis of process control systems (identification of failure modes in control systems' components and research on functional modelling methodologies), safety and reliability analysis of wind turbines.

*Carsten D. Gronberg, M.Sc. (Elec.Eng.).* Risø from 1967. Electronics Department 1967-78. Safety Department 1978-83. Risk Analysis Group from 1984. Main activities: Human factors, emergency management, risk communication, risk management.

*Hans E. Kongso, M.Sc. (Mech.Eng.),* Senior Scientist. Risø from 1957. Research reactor DR2 1957-63, Department of Energy Technology 1963-84. Risk Analysis Group from 1984. Main activities: Computer codes for reliability and consequence assessment, and reliability and risk assessment of nuclear and industrial plants.

*Igor O. Kozin, Ph.D.,* Obninsk Institute of Nuclear Power Engineering, Obninsk. Risø from August 1994. Main activities: development of databases for collecting and analyzing failure and maintenance data, reliability and uncertainty analysis.

*Kurt Lauridsen, M.Sc. (Elec.Eng.), Ph.D. (Nuclear engineering),* Senior Scientist. Risø since 1974. Department of Energy Technology 1974-87, working with nuclear safety and industrial risk analysis. Department of Informatics 1987-90. Risk Analysis Group from March 1990. Main activities: Reliability analysis, risk management.

*Dan S. Nielsen, M.Sc. (Elec.Eng.).* Risø from 1962. Electronics Department 1962-84. Risk Analysis Group from 1984 until December 1994. Main activities: Risk analysis of individual plants, physical modelling for consequence assessments.

*Lars Nyborg, M.Sc. (Chem.Eng.). Ph.D.* student at Risø from 1994. Subject: A socio-technical approach to risk management. The impact of socio-technical factors on the overall safety performance of industrial organizations is analyzed.

*Soren Ott, M.Sc. (physics), Ph.D. (Turbulence theory),* Senior Scientist. Risø from 1985. Main activities: Models and computer codes for consequence assessment; dense gas dispersion and flame experiments.

*Jette Lundtang Paulsen, M.Sc. (Mech. Eng.).* DTH 1972. From 1972-80: Research reactor DR3. From 1980-86: Uranium Extraction project. From 1986-90: Department of Informatics. From 1990: Department of Systems Analysis. Main activities: Maintenance planning, software development, interface systems.

*Birgitte Rasmussen, M.Sc. (Chem.Eng.), Ph.D.,* Senior Scientist. The Technical University of Denmark from 1981-84. Risø from 1984. Main activities: Risk assessment of industrial activities, hazard identification, risk management, risk communication.

*Lene Smith-Hansen, M.Sc. (Chemistry).* Risø from 1986. Main activities: Risk assessment of chemical plants, toxic effects from releases and assessment of chemical warehouse fire consequences.

## UNEP Collaborating Centre on Energy and Environment

*John Mobjerg Christensen, M.Sc. (Eng.) Ph.D.* Danish National Agency of Technology 1980-83, R&D initiation and administration, Oilconsult, Consulting Engineers and Planners 1983-84, R&D Energy Planning, NRSE projects. Risø from 1984. Energy Systems Group 1984-88, Energy planning in developing countries, project analysis tools and methods. Programme Officer, Energy Unit, United Nations Environment Programme 1988-90. Head of UNEP Collaborating Centre on Energy and Environment from October 1990. Main activities: energy-environment planning in developing countries, project initiation, UN contacts and coordination.

*Pramod Deo, M.Sc. (Physics) Ph.D. (Infrastructure Economics).* Senior development administrator with 23 years of experience in the Indian State and Central Governments. Founder Director of state and national level energy institutions namely Maharashtra Energy Development Agency (1986-88) and Energy Management Centre (1989-93). Research Engineer at Asian Institute of Technology, Bangkok 1985-86 and Energy Policy Consultant at World Bank 1992-93. From July 1993 with UNEP Collaborating Centre on Energy and Environment as Senior Energy Economist. Main activities: energy-environment planning in developing countries, project development and management, technical support to UNEP.

*Kirsten Halsnæs, M.Econ.,* Senior Scientist. Danish Ministry of Housing and Building, 1983. Risø from 1987. Energy Systems Group until end of 1992 with the main activities: Methodologies for energy and environmental modelling. From January 1993 with UNEP Collaborating Centre on Energy and Environment with the main activities: The Economics of Greenhouse Gas abatement, methodologies for abatement cost assessment in developing countries, multi criteria assessment for environmental impacts of energy systems. Principal lead author of the IPCC Second Assessment of the Socio-Economics of Climate Change.

*Jiming Hao (Professor at the Department of Environmental Engineering at Tsinghua University, People's Republic of China)* worked at the UNEP Centre for six months, from March to October 1994, as a guest researcher, with fellowship funds provided by the Commission of European Community (EC), to work on modelling and scenario development. Professor Hao has been involved in the project "Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China" as a consultant on energy policy since the start of the project in 1993.

*Gordon A. Mackenzie, B.Sc. Ph.D. (Physics),* Senior Scientist. Guest researcher at Risø 1974-78. Lecturer at Edinburgh University 1978-79. Energy Systems Group from 1980. 1984 to 1987 Energy Adviser/Deputy Director at Department of Energy, Zambia. From February 1988 until February 1990 leader of Environmental Modelling Group. From October 1990 with UNEP Collaborating Centre on Energy and Environment as senior energy planner. Main activities: integrated energy/environmental models, energy and environment in developing countries, environmental database. Editor of Centre publications and newsletter and electronic information systems (Internet and World Wide Web).

*Umme Salma, (Econ). Ph.D.* Risø from August 1993 until December 1994. Specilization in economic modelling. Started career as an Economist with the Bangladesh Government. Ph.D. scholar and later Research Associate at the Australian National University during 1985-93. Research area covered: macroeconomic and distributional consequences of changes in government policies in general as well as in partial equilibrium framework. Work at Risø: energy-economy interactions and social cost-benefit analysis.

*Joel N. Swisher, M.S. (Mech. Eng.), Ph.D.,* (Env. Eng.). Solar Energy Research Institute (U.S.) 1980-83, consultant to New Zealand Ministry of Energy 1984-85, research engineer with Architectural Energy Corp., Colo., U.S.A. 1986-88. Private engineering consulting practice 1988-1992. Visiting Research Engineer at Lund University, Sweden 1991-93. Main activities: integrated energy-environmental planning in developing countries, electric utility planning models, bottom-up analysis of national costs of reducing carbon emissions, training in energy end-use analysis.

*Arturo Villavicencio, M.Sc. (Math.)* National Energy Institute (Ecuador) 1979-85. Energy Planning Consultant for the Latin American Energy Organisation, CEC and World Bank 1985-88. Energy Adviser at OLADE 1988-90. From May 1991 with UNEP Collaborating Centre on Energy and Environment. Main activities: Energy/environmental models, integrated energy-environment planning in Latin America.

## Short term Guest Researchers

*Mr. Ding Yongfu, Senior Engineer,* Guangxi Environmental Protection Bureau, China.
From 1 August - 31 August 1994.

*Ms Li Dianlin, Senior Engineer,* Research Academy of Environmental Sciences, Beijing, China.
From 1 August - 31 August 1994.

*Ian Thomas Cameron,* Brisbane, Queensland. Guest researcher from 18 January-19 February 1994.

## Programmer

*Soren Præstegaard, datanom.* Regnecentralen 1973-79. Risø from 1979. Datanom with special subject: Optimization completed 1985 at EDP-school, Copenhagen. Working on simulation models, graphics, and general user support.

## Secretaries

*Maria M. Andreasen*
*Gytha Egelund*
*Vivi Nymark Hansen*
*Jette Larsen*
*Irma Strandvad*

## Research Technician

*Erling Johannsen*

## Temporary Staff

*Rasmus Norgård, (Agro.Econ. student),* until January 1994.
Energy modelling.

*Morten Nielsen (M.Sc. student),* from 1 March. Software documentary; development of experimental facilities under the MATE project.

*Rosa Villavicienco, M.Sc.* from 1 February to 1 July. Coordinator for international conference in "National Action to Mitigation Global Climate Change"

# Bibliografic Data Sheet

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The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1994. The department is made up of the Cognitive Systems Group, the Risk Analysis Group, the Energy Systems Group, and the UNEP Collaborating Centre for Energy and Environment. The report includes lists of publications, lectures and staff members.

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